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Pleistocene Stratigraphy of Northwestern Pennsylvania

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PREFACE

The bedrock of northwestern Pennsylvania is covered by surficial material — glacial drift — brought from the northwest by a series of continental glaciers. The drift is composed of sheets of till — a mixture of clay, silt, sand, and stones — and layers and masses of sand and gravel. The thickness of this glacial drift over the bedrock is from a few inches to several hundred feet, but generally is from 20 to 80 feet.

The surface extent of each till sheet and of the surface sand and gravel deposits has been shown in 1959 in Bulletin G 32 (Shepps and others, 1959) and in the large map accompanying it. The information provided in that bulletin has been of great value to engineers in showing what materials may be expected at the surface and in pointing out favorable locations for sand and gravel production. It has been useful to soil scientists to show surface extent of different parent materials from which the soils have been formed.

In the past 10 years, excavations for Interstate Highways 79 and 80, for greatly expanded strip mining for coal, and quarrying for limestone have provided scores of miles of exposure of glacial materials far below the land surface. It is now possible to show in detail the sequence and variation in composition of the lower drift units. These are described in the present report and shown in maps, and especially in cross sections, some of which are hundreds of feet and even hundreds of yards in extent thus demonstrating their lateral continuity. This atlas of sections of glacial materials, most of them extending from the surface to the bedrock, is the most extensive and complete three dimensional picture of the glacial materials in any area of comparable size in the world and is a significant "first" for the Pennsylvania Geological Survey, which has pioneered in so many other geological presentations over the past century and a quarter — mountain structures, diagrams of physiographic divisions, forms and continuity of coal beds and geometric form of oil-bearing structures, to name only a few.

This report will be of use to engineers in several ways. It is now shown that the unconsolidated material below the surface is different in composition, hardness, and water content from that at the surface, and that excavations for highways, for large structures, and for coal and limestone must take these variations into account in preliminary planning, in excavation programming, and in slope specifications.

The continuity and widespread occurrence of the sand layers between the till sheets, demonstrated in this report and shown in the dia-

grams, must be taken into account in planning excavations and in foundation specifications for large structures. The sand and gravel layers may be water bearing and provide water supplies in areas where surface materials may appear to be unpromising for water supplies. The report also shows that in some places one or more buried sand layers expand to a thickness of 20 feet or more and present special problems of construction or special opportunities for water supply.

This report demonstrates the existence of considerable bodies of sand and gravel below one or several till sheets. It is now known that these may be encountered in mining and in highway excavations and their exploitation for commercial purposes should be considered.

Further information for soil scientists is supplied by this report. In places the surface layer of drift is so thin that the soil is developed on a lower drift and is thus a different type from that found on adjacent surface drift.

Those concerned with other environmental problems will find this report of use. An example is use by those dealing with waste-disposal planning. This report shows that the unconsolidated materials below the surface are different from those at the surface and therefore may accept liquids for disposal at different rates. The rate may be greater or lesser, and thus be more or less favorable than that of the surface material. The buried sand and gravel layers must be taken into account, as they may allow introduced liquids to travel considerable distances. Now that it is known that this situation may exist, it can be considered in planning projects.

This report provides further information from which the history of advances and retreats of the ice sheets in northwestern Pennsylvania may be determined and thus contribute to a better understanding of the origin of the landscape and materials of this part of the State.

CONTENTS

ILLUSTRATIONS

FIGURES

TABLES

PLEISTOCENE STRATIGRAPHY OF NORTHWESTERN PENNSYLVANIA

by
George W. White, Stanley M. Totten, and David L. Gross

ABSTRACT

Northwestern Pennsylvania is covered with deposits brought by continental ice sheets which advanced onto the Allegheny Plateau from the Erie basin.

The oldest glacial deposit, of probably early Pleistocene age, is the Slippery Rock Till. It is not a surface deposit, but is exposed in strip mines in Mercer and Lawrence Counties. It is always weathered to the base, but crystalline fragments are preserved in it.

The Mapledale Till is the surface material in a 1 to 5 mile wide marginal belt from Beaver County at the Ohio boundary to Warren County, near the New York border. It is present at many places in the glaciated area below drift of later age. The Mapledale Till is a coarse till with a very high proportion of sandstone fragments and a very low carbonate content. It has a mean sand content of 44.0 percent and a mean feldspar content of 5.4 percent. At many places, the upper part of the unit consists of a thick paleosol. The Mapledale Till may be Illinoian in age and the associated paleosol of Sangamonian age.

The Titusville Till is the surface material in a narrow belt in the southeastern part of the area and forms the bulk of the drift in the remainder of the glaciated region. Ten miles or more within the margin, it is as much as 75 feet thick. The Titusville Till is a sandy, pebbly till, which oxidizes to olive brown. The mean sand content is 45.4 percent; the mean feldspar content is 12.1 percent. At some places it consists of at least three separate sheets, separated by sand layers as much as 20 feet thick. It was deposited approximately 40,000 years ago, as determined from C-14 analysis of peat buried beneath this till at Titusville. Its age is, therefore, early Wisconsinan, and it is correlated with the Altonian drift of the Mississippi Valley. The lower part of a moderately developed paleosol is preserved on the buried Titusville Till at a few places.

Kent Till overlies Titusville Till and is the surface material in much of the area. It is usually not over 10 feet thick. It is overlain by later tills in the western and northwestern part of the area. The Kent Till is a sandy till that oxidizes to a yellow-brown color. Its mean sand content is 43.0 percent and its mean feldspar content is 14.1 percent. It is approximately 23,000 years old, as determined from associated organic material near Cleveland, Ohio. It is, therefore, the oldest deposit of "late Wisconsinan" age, and is correlated with the early Woodfordian of the Mississippi Valley sequence.

Lavery Till occupies a belt several miles wide across northwestern Mercer, central Crawford, and southeastern Erie Counties. It is generally less than 10 feet in thickness. It is a silty till with only moderate pebble content. It oxidizes to a chocolate-brown color. The Hiram Till occurs in a narrow belt in the northern part of the area. It is a silty to clayey till which oxidizes to a dark-brown color. The Ashtabula Till occurs in a very narrow belt just south of Lake Erie in the extreme northern part of the area. This till is a silty till which oxidizes to a brown color.

First order trend surface shows that the sand content of the Titusville Till increases at a rate of 0.33 percent per mile toward the margin and its feldspar content decreases 0.41 percent per mile.

The history of Pleistocene events of northwestern Pennsylvania is as follows: an early Pleistocene (either Nebraskan or Kansan) ice sheet deposited the Slippery Rock Till, after which followed a long period of weathering and erosion. In the following glaciation, probably of Illinoian age, the Mapledale Till was deposited, followed by long erosion and weathering, which produced a thick palcosol on the Mapledale Till. In early Wisconsinan (Altonian) time, several ice advances deposited the thick Titusville Till; the ice reached Titusville approximately 40,000 years ago. A period of weathering, corresponding to the Farmdalian episode in the Mississippi Valley, formed a moderate paleosol on the Titusville Till. At the beginning of the late Wisconsinan (Woodfordian) advancing ice deposited the Kent Till about 23,000 years ago. This was followed by ice advances, each of which successively reached less far, to deposit the Lavery, Hiram, and Ashtabula Tills.

INTRODUCTION

PURPOSE AND SCOPE

In the past several years extensive new outcrops of glacial drift have become available for study in Lawrence and Mercer Counties through strip mining and quarrying and in these counties and in Crawford County through interstate highway construction. Some new road construction in Venango, Warren, and Erie Counties has also provided new outcrops. Strip mining and quarrying reveals the total section of glacial material overlying the bedrock and thus provides an opportunity to study the lower materials, some places as much as 100 feet below the surface of the ground. The recent publication of new topographic maps in northwestern Pennsylvania with a scale of 1:24,000 has also facilitated geological studies.

Because the surface materials and the surface morphology of northwestern Pennsylvania had previously been studied and mapped (Shepps and others, 1959) the principal purpose of the present investigation was to study the older (early Wisconsinan and pre-Wisconsinan) till units below the surface drift. The major objectives were to determine the composition of the older drifts, to determine their stratigraphic relations and divisions, and to correlate them with the same age drifts which had been mapped at the surface to the southeast. Surface observations of these tills in the outcrop areas were included in order to compare the character of the earlier tills at the surface with their subsurface character-

istics, particularly the buried weathered zones, where these were preserved. A brief description of the younger Lavery, Hiram, and Ashtabula Tills, which are the surface material over about one third of the glaciated part of northwestern Pennsylvania, is included for completeness.

The study was confined to the Allegheny Plateau and did not include investigation of outcrops in the Lake Plain north and northwest of the plateau. The study in the northeastern part of the plateau, especially in Erie County and northern Crawford County, was much less detailed than elsewhere because strip mines are not present there and because the topography is less rugged. Interstate highway construction there does not require deep cuts and only a very few sections are deep enough to reveal the tills. Sections do exist along the valleys tributary to Lake Erie (Conneaut Creek and tributaries) in northern Erie County, but these are so far from other sections to the south, where the lower units can be identified by tracing, that a study of these sections was not included in the present study.

LOCATION AND GEOLOGICAL SETTING

The area of this study is that part of northwestern Pennsylvania in which glacial drift forms all or part of the surficial material (Fig. 1). This includes all of Erie, Crawford, and Mercer Counties, and parts of Warren, Venango, Butler, Lawrence, and Beaver Counties. As already noted, only a part of Erie County was studied in this investigation.

The area in northern Erie County is within the Lake Plain. From an elevation of 573 feet at Lake Erie, the plain rises to more than 1,000 feet several miles from the lake. Along an abrupt escarpment from 4 to 8 miles south of Lake Erie the surface rises to the Allegheny Plateau, which has a general elevation from 1,200 feet on the west to as much as 2,100 feet on the east, with a relief ranging from 300 feet on the west to as much as 800 feet in the east. The increased elevations to the east and northeast were the controlling factors of the margins of the various ice sheets which invaded the region.

The bedrock of the region consists of Upper Devonian shales, sandstones and siltstones in the northern part of the area in Erie, northern Crawford, and northern Warren Counties and of Mississippian sandstones, shales and Pennsylvanian sandstones and shales, with minor limestones and coals in the remainder of the area.

Longer discussions and descriptions of the bedrock geology, topography, drainage, and early drainage systems will be found in the reports of Shepps (1955), Tomikel and Shepps (1967), Sitler (1957) and Shepps and others (1959).

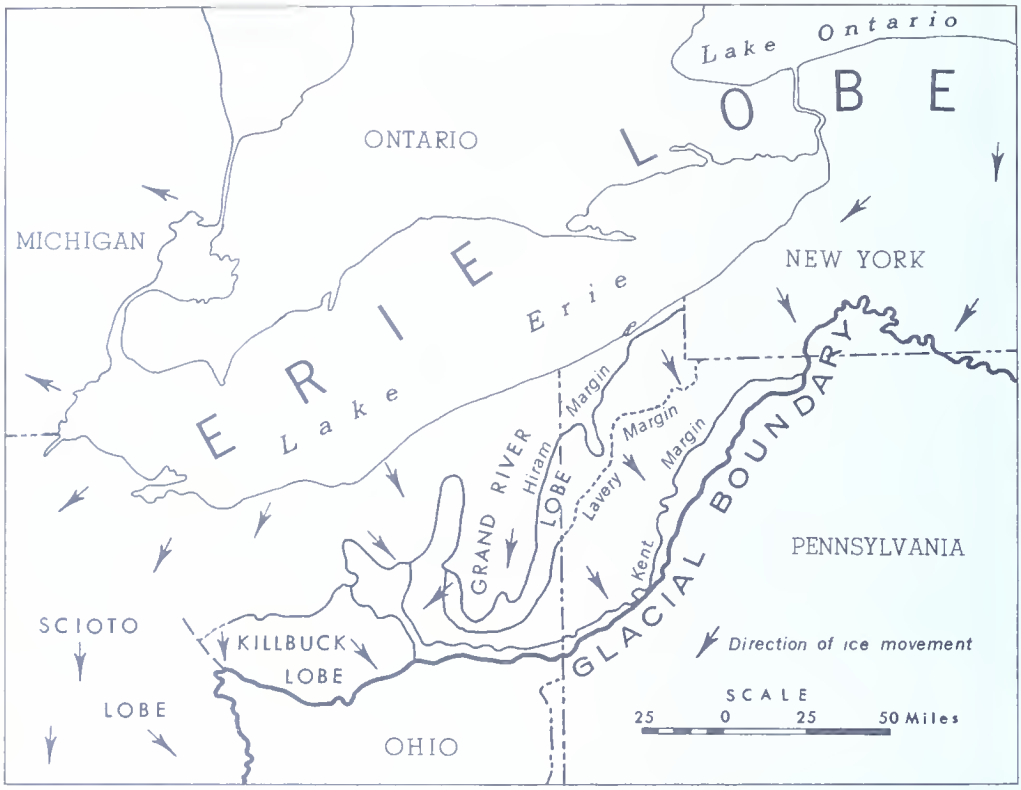

Figure 1. Distribution of ice lobes in western Pennsylvania and adjacent areas.

PREVIOUS WORK

Earlier reports on the glacial deposits of northwestern Pennsylvania have been reviewed in detail by Shepps (1955), Sitler (1957), and Shepps and others (1959)*. Only certain ones need be discussed here. Among the early works that should be mentioned, however, are those on the glacial boundary by H. C. Lewis, assisted by G. M. Wright (Lewis, 1882) and the monographic publications of Leverett in 1902 and 1934. These papers are concerned with surface drifts and morphology and have little, if any, information about subsurface stratigraphy.

Forerunners of the present study are reports by Shepps (1955), who studied the glacial geology of northwestern Mercer, western Crawford, and southwestern Erie County in 1952 and 1953. In 1954 and 1955, Sitler studied the area to the south of Shepps in southern Mercer, Lawrence, northwestern Beaver, and western Butler Counties and presented a report in 1957 that included his study of the rock and mineral fragments,

*Repeated references will be made to "Glacial Geology of Northwestern Pennsylvania" by Shepps, White, Droste and Sitler, 1959. It will be referred to in the text as "Bulletin G-32".

particularly the heavy minerals. In 1956 and 1957, John B. Droste, with the assistance of R. W. Doehler in 1956 and J. C. Tharin in 1957, mapped the glacial deposits of northern and eastern Erie County, central and eastern Crawford County, Warren County, Venango County, and northeastern Mercer County. This work was incorporated in Bulletin G-32 and in reports on the clay minerals (Droste, 1956a and b; Droste and Doehler, 1957; Droste and Tharin, 1958). Tharin (1958) reported on textural studies of late Wisconsinan tills in northwestern Pennsylvania. Colored maps at a scale of 1:62,500 of the whole glaciated area of northwestern Pennsylvania are available in Shepps (1955), Sitler (1957) and in manuscript files of the Pennsylvania Geological Survey. Those of Droste and his assistants are also in the files of the Pennsylvania Geological Survey.

These studies are all summarized in Bulletin G-32 which includes a large colored map at a scale of 1:125,000 showing the surface outcrop of all of the tills and their morphological expression. Present investigation has confirmed the accuracy of this mapping with two exceptions. One small exception is in Warren County in the border of the oldest drift; the other is in the extension of the Lavery Till farther south of the Lavery moraine, which was formerly believed to mark its outer margin. Bulletin G-32 and the reports on which it is based all contain measured stratigraphic sections. At the time those reports were prepared, sections, especially north of central Mercer County, were not readily available because of lack of deep excavations. The primary purpose of those previous studies was the mapping of the surface drifts to show their composition, morphologic forms and their boundaries, in contrast to the present which is concerned mainly with stratigraphy, and which forms a continuation and "subsurface extension" of the earlier work.

FIELD WORK FOR THIS REPORT

The field work for this report was conducted in the summers of 1964, 1965, and 1966, and a few days in the summer of 1967. In the summer of 1964, White and Totten worked mainly in Mercer, Venango, and northern Lawrence Counties. In the summer of 1965, White, assisted by Gross, worked in Crawford and Warren Counties and Totten, assisted by Mr. Stephen A. Moran, worked in Lawrence County and adjacent areas in Ohio. In the summer of 1966, White and Totten worked in eastern Crawford, southern Erie, and Warren Counties. Laboratory investigations of the tills, particularly the Titusville Till, were conducted by Gross in the laboratories of the Geology Department at the University of Illinois, Urbana in the academic years of 1965-66 and 1966-67.

Several hundred sections were measured and sampled in detail. Exposures that were continuous for as much as a mile in strip mines,

quarries, and superhighway cuts showed that a section measured at one place might not be the same as a section measured 100 yards away, or even 100 feet away, because of change in thickness of units. Although thicknesses changed and the lowest units were not continuous because of their general preservation only in low places on the bedrock, long exposures do show the "discontinuous continuity" of these units and contribute to the assurance that they can indeed be traced over wide areas.

Vertical sections were generally recorded at the location where the largest number of units were present, and sketches and photographs were made of the whole outcrop or of significant parts of it. In this report only a few columnar sections will be shown graphically or in tables and the data will be presented mainly by means of horizontal sections, so that a two dimensional, rather than a one dimensional record can be presented. As quarry and strip mine walls do change direction, it was possible to see the drift units in three dimensions and to take such observations into account in our report. Also, by repeated observations of certain strip mines as the stripping advanced it was possible to study them in three dimensions. Figures 18, 19, and 20 show the changes that can be observed as a strip mine face advances. These longitudinal sections, determined by actual visual continuity in the field, comprise the largest collection so far published to show the relation of till and other drift units over a considerable distance. Longitudinal sections that show several tills are placed in Appendix II for more ready comparison among them (Figs. 17-43). The locations are shown in Figure 16.

One advantage of studying the tills in strip mine cuts is that the excavations always extend to bedrock. Glacial drift does extend to depths of at least 200 feet and possibly more in some deep valleys, but no cuts extend to this depth. The deep valley extending northeast-southwest through Grove City is well shown on recent maps by Poth (1963, p. 44-45, pl. 2) and deep valleys now more or less filled with glacial material in the Neshannock 15′ quadrangle are well shown in the map and cross sections constructed by Carswell and Bennett (1963, pls. 1, 2, and 3). Determination of the stratigraphy of these thick deposits will require study by cores and samples obtained from closely spaced drilling.

ACKNOWLEDGEMENTS

The field work and laboratory study was supported by National Science Foundation Grant GT 2675 for "A study of the stratigraphic relation, classification, and correlation of early Wisconsinan and 'pre-Wisconsinan' tills of northwest Allegheny Plateau." We are grateful for the support which made this study possible.

Mr. Stephen Moran provided able and stimulating field assistance in 1965 and his continued interest and fruitful discussions are gratefully acknowledged. Mr. David Mari assisted most efficiently with some of the laboratory work.

Conferences with Dr. Arthur A. Socolow, State Geologist, Dr. Donald M. Hoskins, Assistant State Geologist, and the late Dr. V. C. Shepps, formerly of the Pennsylvania Geological Survey, have been most helpful in developing the form and graphic features of this report. We are grateful for their encouragement and helpfulness.

Mrs. Nancy Pace and Miss Carolyn Rice not only typed repeated drafts of the manuscript, but helped in checking tables and references.

Illustrations for this report were prepared by Mr. Albert Van Olden, illustrator for the Pennsylvania Geological Survey.

STRATIGRAPHY

INTRODUCTION

At various times in the Pleistocene, ice sheets moved into the Erie Basin and spread out from it southward in a series of lobes controlled by the positions of highlands and lowlands. All of the drift of northwestern Pennsylvania was deposited by lobes of ice which repeatedly advanced from the Erie Basin in a direction controlled by the Grand River lowland in Ohio, just west of the Pennsylvania line. The drift of northwestern Pennsylvania, therefore, is the drift of the eastern part — essentially the eastern half — of the Grand River lobe, in which ice moved in a general southeastward direction. The position of these lobes and the relation of the Grand River lobe to Pennsylvania is shown in Figure 1. There is some indication from the mineral trend distributions in the various tills that flow of ice in each of the advances was not always in exactly the same direction, but it appears not to have diverged very much from the general southeastern direction.

The number and extent of fluctuations of the ice in late Wisconsinan time are known in considerable detail from earlier studies (Shepps and others, 1959). The present investigation shows that in early Wisconsinan time the Titusville Till was deposited by a series of advances which laid down a series of till sheets here described for the first time. Pre-Wisconsinan ice advances are less well known, but we can now report a major advance in Illinoian (?) time that deposited the Mapledale Till, a till possibly deposited in two sheets. A still earlier ice advance, which may be early Pleistocene, deposited the now deeply weathered Slippery Rock Till.

These deposits were studied and mapped and described as rock stratigraphic units and are given names of formational rank. The deposits are discussed in the usual stratigraphic order, that is, from the oldest to the youngest. The classification of the glacial deposits is given in Table 1. Their surface distribution is shown in Figure 2.

The till sheets of northwestern Pennsylvania are differentiated on the basis of texture, mineral and lithologic composition, color, stratigraphic position, and weathering horizons. Each of these characteristics will be treated in a discussion of the separate units. It may be noted that the most obvious and positive method of separation of the various till sheets is preservation of the weathered zone with a soil — a paleosol beneath an unweathered younger till sheet. Lacking a paleosol at a given outcrop, other criteria must be used. In extensive exposures in northwestern Pennsylvania, however, it was in many places possible to trace adjacent fresh tills to a position in which a paleosol, part of a paleosol, or at least part of a weathered zone was preserved on the lower one, thus confirming separations originally established on the basis of mineral or other characteristics.

PRE-GLACIAL OR VERY EARLY PLEISTOCENE DEPOSITS

In strip mines at Valcourt, Liberty Township, Mercer County, now restored to original contour, orange-red to dark-brown, silty clay lay between the bedrock and weathered Slippery Rock Till, the oldest till of the region. The clay ranged in thickness from 2 to 5 feet over a distance of 300 yards (Fig. 21). It was partly iron-cemented, having the characteristic of plinthite (Soil Survey Staff, 1960, p. 62). The upper contact with the Slippery Rock Till was sharp and the lower contact with weathered shale beneath was likewise sharp. Although deeply weathered, it appeared to be a definite deposit and not the result of in situ weathering of shale. The material did not appear to be of glacial origin because it contained no foreign pebbles as does the weathered Slippery Rock Till that overlies it on the south or as do the Mapledale or Titusville Tills that overlie it on the north.

The clay at Valcourt strongly resembles material beyond the glacial boundary in a strip mine in the western part of Parker (Foxboro, 15′ quadrangle) near the Butler-Clarion county line, at the intersection of State Road and Eau Clair Road. This deposit was called to the writers' attention by Dr. F. W. Preston and Mr. Heber Lessig. The deposit was in a former basin near the hilltop, 150 feet above the Parker Strath level at its type locality (Butts, 1904, p.3) in the valley of the Allegheny River. The depression in the shale and Vanport Limestone 200 yards in length

Table 1. *Glacial deposits in northwestern Pennsylvania*

Epoch	*Stage*	*Substage*	*Unit*	*Material*
PLEISTOCENE	Wisconsinan	Late (Woodfordian)	Ashtabula Till	Silty till, oxidizes dark brown
			Hiram Till	Clayey till, oxidizes chocolate brown
			Lavery Till	Silty till, oxidizes dark brown
			Kent Till	Sandy till, oxidizes yellow brown
		Farmdalian		Weathered till and basal paleosol
		Early (Altonian)	Titusville Till (several separate sheets)	Sandy, pebbly till, oxidizes olive brown; sand layers may separate till sheets
	Sangamonian (?)			Weathered till with silt loam paleosol
	Illinoian (?)		Mapledale Till (two sheets?)	Stony, sandstone-rich till, oxidizes yellow brown; very low in carbonate
	"Pre-Illinoian"		Slippery Rock Till	Deeply weathered till and paleosol with erratic pebbles

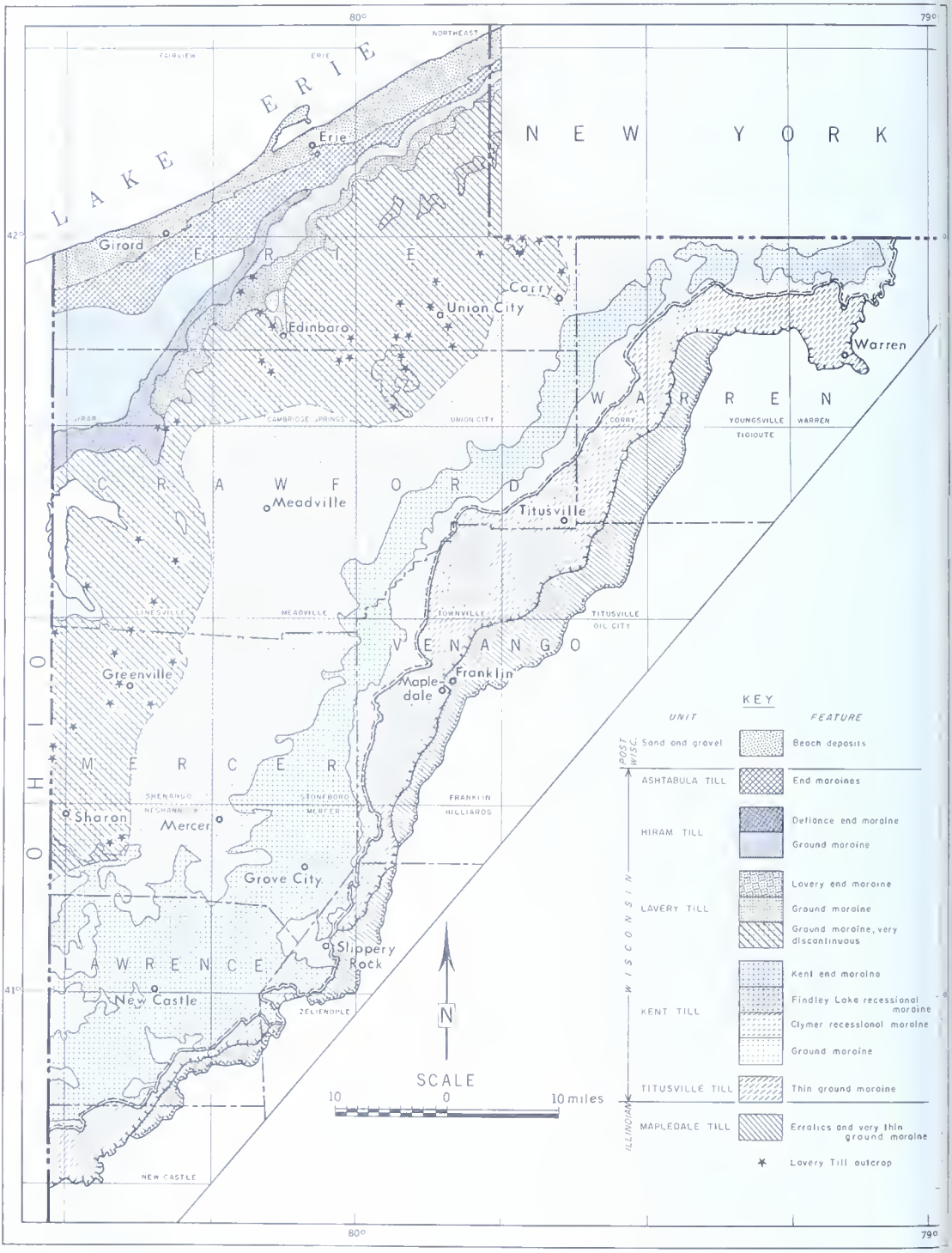

Figure 2. Distribution of glacial drift in northwestern Pennsylvania (modified from Figure 4 of Bulletin G 32, Shepps and others, 1959).

and 30 feet in depth, was filled with clay which was massive, silty, light yellow to tan, with reddish-pink zones up to 1 foot in thickness. Sandstone channers — flat pieces of sandstone and siltstone 2 to 4 inches in long dimension — were scattered throughout the entire section, but were more common near the base. The basal part was evidently colluvium from surrounding hillsides, but the presence of sandstone pieces higher in the section, "floating" in clay, is more difficult to explain. No indication of bedding was observed. The color and general appearance was reminiscent of many of the Tertiary deposits of the Atlantic Coastal Plain.

From the deposits outside the glacial boundary at Parker and beneath the glacial deposits at Valcourt, it is apparent that some early Pleistocene or pre-Pleistocene deposits were laid down on uplands in northwestern Pennsylvania. Perhaps they may have some correspondence in age and origin to the Calcutta Silt described by Lessig (1963) from uplands in Columbiana County, Ohio, to which he assigned a "very early Pleistocene" age.

PLEISTOCENE DEPOSITS

SLIPPERY ROCK TILL

The Slippery Rock Till is the lowest and the oldest unmistakably glacial deposit that occurs in northwestern Pennsylvania. It is named for an exposure in the limestone quarry of the Vanport Stone Company located just east of Wolf Creek, ½ mile southeast of the Courtney Mills Bridge, Liberty Township, Mercer County, 3 miles north-northwest of the village of Slippery Rock (Slippery Rock 7½′ quadrangle). The Slippery Rock Till is not known at the surface, but is entirely a subsurface unit which is exposed only in excavations. The type section at the quarry is illustrated in Figure 22. The four digit numbers in this and other sections, and in the diagrams, are the numbers assigned to samples collected for analysis, which are listed in tables elsewhere (Gross, 1967). The location of each figure is shown on the map, Figure 16, and where required for clarity, locations of numbered samples are also shown in Figure 16. The section is as follows:

Type Section of the Slippery Rock Till

	Unit Thickness Ft.	In.	*Aggregate Thickness* Ft.	In.
Wisconsinan:				
Kent Till:				
Till, gravel, and sand, weathered	5	0	5	0
Till, sandy, yellowish-brown, calcareous	3	6	8	6
Titusville Till:				
Till, sandy, olive-brown, calcareous	3	6	12	0
Till, sandy, pebbly, dark olive-gray calcareous, (3149)	5	0	17	0

	Unit Thickness Ft.	In.	Aggregate Thickness Ft.	In.
Illinoian (?):				
Mapledale Till:				
Loam, clayey, yellow and brown	0	6	17	6
Loam, very stony, yellow and brown	0	6	18	0
Loam, sandy and clayey, mottled	0	6	18	6
Loam, clayey and sandy; yellow-brown and gray, derived from till	1	6	20	0
Till, very sandy, yellow and brown, deeply weathered	0	6	20	6
Sand and gravel	3	0	23	6
Till, sandy, yellow-brown, somewhat weathered	2	0	25	6
Till, gray, noncalcareous (3150)	2	0	27	6
Pre-Illinoian (?):				
Slippery Rock Till:				
Loam, reddish-brown, hard, iron-cemented (3201)	0	9	28	3
Clay loam, drab to geenish-gray (3202-03)	1	6	29	9
Loam, clayey, sandy, reddish-brown, contains few crystalline pebbles (3204)	1	0	30	9
Clay, olive-gray to green; looks like weathered shale	2	0	32	9
Shale, upper part weathered	6	0	38	9

Location and Extent

Slippery Rock Till is present in a strip mine at Valcourt, Liberty Township, Mercer County, 2¼ miles east of the type locality, shown as unit 9 in Figure 21, and was observed in a strip mine just west of the rest park on the southbound lane of Interstate Highway 79, Plain Grove Township, Lawrence County, 1 mile south of the northeast corner of that county, shown as unit 8 in Figure 23. At several other strip mines in Mercer and Lawrence Counties indications of weathered material underlying fresh Mapledale Till were observed on strip mine walls, but in such inaccessible positions that close examination was not possible. It appears to underlie weathered Mapledale Till in the valley of West Pithole Creek in Venango County (Fig. 3, section 3212).

The Slippery Rock Till is not known to extend beyond the margin of the later Mapledale Till. It is possible that the ice which deposited the Slippery Rock Till extended only to about the limit reached by the later Mapledale ice advance, but it may have extended farther.

Composition and Weathering Character

No unweathered Slippery Rock Till has been observed. The weathered material is greatly altered, but the original material seems to have been sandy, pebbly till. Only a few crystalline pebbles have been observed in the weathered material and it is not known what proportion of material other than sandstone pebbles the unweathered till contained. The very clayey character of the weathered material may indicate that the original till had about 10 percent granitic fragments, and probably some limestone pieces.

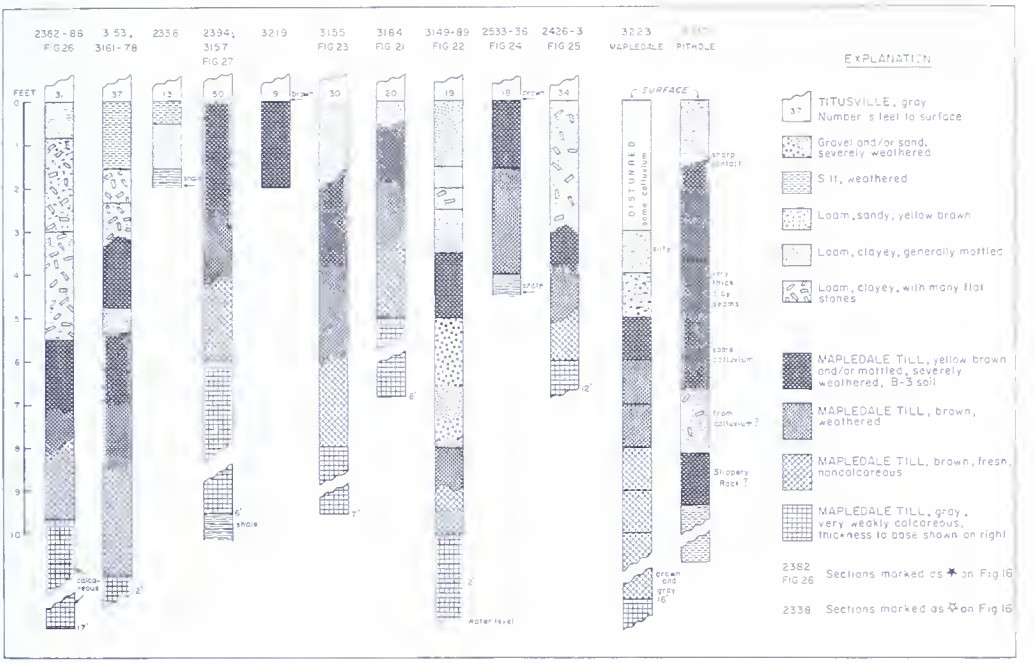

Figure 3. Columnar sections showing paleosols of Sangamonian (?) age on buried Mapledale Tills, and surface soils on Mapledale Till.

Location and overlying stratigraphic units of the columns are shown in the figures of longitudinal sections indicated; others not so indicated are located as follows:

3153, 3161-78 Strip mine S of highway 1/8 mile E of W line, 1¼ miles S of N line, Worth Twp., Mercer Co.

2338 Strip mine ¼ mile N of State Highway, 1¾ miles E of Harrisville, Marion Twp., Butler Co.

3219 Borrow pit for new highway location of U. S. Route 6 (Clarendon Road), S of Allegheny River, Mead Twp., Warren Co.

Sections of surface soils and weathering units shown in Column 3223, the type section at Mapledale; and in Column 3212, on N bank of West Pithole Creek, 150 feet E of highway bridge, 200 yards N of township line, 1½ miles W of township line, and 1¼ miles NW of Pithole State Park, Oil Creek Twp., Venango Co.

At some places in strip mine excavations, the bedrock upon which the younger Mapledale or Titusville Tills rest is weathered and in some places paleosol is present. If no foreign pebbles were found in such a paleosol — even if rounded sandstone pebbles were present — it was not positively identified as Slippery Rock (Figs. 24, 25), but the possibility remains that such a paleosol may contain unrecognized remnants of deeply weathered Slippery Rock Till.

Stratigraphic Position

The Slippery Rock Till lies upon bedrock, which in some places appears in its upper surface to be even more weathered than the till and may represent a pre-Slippery Rock episode of weathering. At Valcourt (Fig. 21), the Slippery Rock Till is underlain by strongly weathered silty clay which may be either very early Pleistocene or pre-Pleistocene in age.

The Slippery Rock Till is overlain by Mapledale Till. Where the overlying Mapledale Till is thin and much weathered, the two weathered tills appear to form a unit, but can be separated by tracing the Mapledale laterally to a place where it becomes thick enough to show its fresher character.

Age and Correlation

The age of the Slippery Rock Till is uncertain. It is definitely older than Mapledale Till and is probably pre-Illinoian. It cannot be correlated with other older drifts in other states, but it may be related to some of the deeply weathered material south of Youngstown, Ohio, described by Totten and others (1967; in press). The Slippery Rock Till may have some relation to the much weathered drift with a mature paleosol at Elkton, Columbiana County, Ohio, 10 miles west of the Ohio-Pennsylvania line, described by Lessig and Rice (1962). Its relationship to the "pre-Illinoian" or Jerseyan drift of northeastern Pennsylvania described by Leverett (1934, p. 81) is unknown.

Possible Drift Beyond the Mapledale "Illinoian (?)" Boundary

It should be noted that the supposed drift of Kansan age reported in northwestern Pennsylvania by Leverett (1902, p. 228-252) and the "pre-Illinoian" deposits reported later (Leverett, 1934, plate 1 and p. 94) are based almost entirely on the position of certain outwash terraces and not on till deposits (Shepps and others, 1959, p. 20). Leggette (1936, p. 28) has reported that "At several places south of the generally recognized glacial boundary erratic boulders have been found in such topographic positions that they seem not to be related to the drainage from the Illinoian ice. Leverett (personal communication) suggests that these erratics may be erosional remnants of an old drift sheet, possibly of Kan-

san age." The possibility should be kept in mind that any early, pre-Mapledale Till (Slippery Rock Till or other till) that existed at the surface east of the present margin of the Mapledale Till is now so thoroughly eroded that evidence of its former existence in this greatly dissected country may be almost entirely removed. A granite boulder reported near Tidioute (Leggette *in* Leverett, 1934, p. 96) may be a remnant of an early, now almost completely disappeared drift. If an earlier drift sheet that extended beyond the margin of the Mapledale Till were composed, as is the Mapledale Till, almost entirely of sandstone fragments, its weathered remains would leave little clear evidence of glacial origin. It may be noted that on the uplands for 3 miles beyond the Mapledale margin sandstone boulders, some of them rounded, are present in positions difficult to explain as having come from local bedrock outcrops. Anyone making investigations in this area should be alert to notice any crystalline rocks in positions where their presence cannot be related to coarse gravel used in road building. Any erratics which might be found are most likely to be quartzite, but possibilities of granitic rocks should not be excluded.

MAPLEDALE TILL

The Mapledale Till, earlier referred to as "outer phase Illinoian" (Shepps and others, 1959, p. 20), is named from exposures at Mapledale, a southwestern suburb of Franklin, Venango County, just north of the Franklin Airport. The type section of the Mapledale Till was measured on the north wall of an excavation for a shopping center lying between a street that was formerly the old U.S. Route 62 and the present Route 62, 1 mile southwest of the City Hall in Franklin and ¼ mile northeast of the road junction of U.S. Route 62 and State Route 8:

Type Section of the Mapledale Till

	Unit Thickness Ft.	In.	*Aggregate Thickness* Ft.	In.
Illinoian?:				
Mapledale Till:				
Soil and disturbed material	3	0	3	0
Silty clay loam, mottled	1	0	4	0
Loam, very sandy and deeply weathered till, mottled	1	0	5	0
Till, severely weathered, mottled	1	0	6	0
Till, sandy, yellow-brown, weathered	1	0	7	0
Till, sandy, dark yellow-brown to brown	3	0	10	0
Till, sandy, dark-yellow brown, very stony, not much weathered, noncalcareous	3	0	13	0
Till, sandy, stony, gray-brown, noncalcareous	1	0	14	0
Till, mixed gray and brown, noncalcareous	2	0	16	0
Till, sandy, stony, gray, noncalcareous	2	0	18	0

Location and Extent

The Mapledale Till is the surface material in a belt ranging from less than a mile to almost 5 miles in width across southwestern Warren, diagonally across central Venango, across northwestern Butler, southeastern Lawrence, and northeastern Beaver Counties (Fig. 2). This is the area shown in Bull. G-32, Plate 1, as "outer phase Illinoian." West and northwest of the belt where Mapledale Till is the surface material, this till is overlain by other tills of younger age. The till extends beneath them west into Ohio. Its extent northward into New York is unknown, but is is assumed to be present there below later tills.

Where the Mapledale Till is the surface material, the thickest till seen was at the type locality where the thickness is more than 18 feet. Mapledale gravel deposits of greater thickness will be described below. At other outcrops, the Mapledale Till ranges from 10 feet to material so thin that it is incorporated in the soil and its existence is difficult to determine. At several localities south and southwest of the Mapledale and Franklin, 6 feet of intensively weathered till is exposed in some road cuts. At most of these 1 to 2 feet of silt overlies the weathered till.

At a few exposures in strip mines, where overlain by younger tills, Mapledale Till as much as 22 feet in thickness has been observed. Such an example in Worth Township, Mercer County is illustrated in Figure 26. At this location the lower part (unit 12) of Mapledale is notably calcareous, in contrast to the upper part which is similar to the usual Mapledale Till with its characteristic high proportion of sandstone fragments and virtual absence of carbonate. This is interpreted as an earlier phase of the Mapledale. It is definitely below, and therefore older than typical noncalcareous, but fresh, Mapledale (units 10 and 11, Fig. 26).

In the cut for the relocation of the Erie Railroad around Shenango Dam northeast of Sharpsville, Mercer County, more than 100 feet of drift is present. This cut was not seen until after the surface had been smoothed and "blurred," but it apparently consists mainly of till, except in the basal 15 feet where gravel is present. The lower 40 feet or more of drift is probably Mapledale Till and lies below 65 feet of mainly gray Titusville Till. The upper part is oxidized, but details are not exposed.

Sections, now covered, were reported in detail by Sitler (1957, p. 27-53) in Mercer and Butler Counties, particularly in the vicinity of Slippery Rock. His sections recorded noncalcareous or very slightly calcareous till, which is otherwise fresh. There is some possibility that more than one Mapledale Till unit was present.

West of the farthest extent of Titusville Till, informative surface exposures of the Mapledale Till exist along new road cuts and in strip mines in Mineral and Irwin Townships, Venango County, in an area

where the Titusville Till is missing. At Wood Corners in northern Irwin Township (Polk 7½′ quadrangle), 3 to 10 feet of intensely weathered Mapledale Till crops out above the bedrock in strip mine cuts on either side of the north-south road. The till is cobbly to bouldery with rare crystalline rocks.

Throughout the area of outcrop of the Mapledale Till, crystalline erratics are rarely found on the surface of the soil and those erratics that are present are almost always quartzite. At some localities their presence is revealed only by diligent search, most favorably in plowed fields. The abundant sandstone cobbles and boulders, generally rounded, are of glacial origin; but actual proof of this origin is confirmed only by their association with crystalline rocks. This makes the mapping of the outer margin of the Mapledale Till area difficult and time consuming. The present investigation has confirmed the excellent mapping of Shepps, Droste and Sitler reported in Bull. G-32, Plate 1. Only one modification, near Youngsville, has been made in the boundary, as noted below.

Composition

The unweathered Mapledale Till, as seen at the type locality and at other outcrops where overlain by later till, is dark gray to bright gray (5Y 4/2 to 4/0). It oxidizes to dark yellow-brown (10YR 4/4) in contrast to the olive-brown (5Y 4/3) of oxidized Titusville Till. The numbers of colors in this report are those in the soil color charts (Munsell, 1954) for standard color designations.

The Mapledale Till is sandy and pebbly with many cobbles and boulders, almost all of which are sandstone. Analyses of four samples of the unweathered till at the type locality range from 45 to 51 percent sand, 20 to 23 percent clay, and 28 to 32 percent silt. The mean composition of all 24 analyzed Mapledale samples is 44 percent sand, 36 percent silt, and 20 percent clay.

At the type locality the feldspar content is 3 percent in three samples and 2 percent in another, but in all samples analyzed, the sand fraction has a mean composition of 95 percent quartz and 5 percent feldspar. The mean feldspar composition is 53 percent K feldspar. As is the case with the younger Titusville and Kent Tills, the feldspar content of the Mapledale Till appears to decrease toward the margin, as will be discussed later, but too few samples are available for statistical testing of this apparent trend.

The carbonate content is less than 1 percent at the type locality and is so low that even weak effervescence with HCl is not evident. The mean carbonate content for all samples is 1.3 percent, about evenly divided between calcite and dolomite. However, it should be noted that at one or two places (Fig. 26) a lower unit of the Mapledale is more calcareous.

Weathering Character

The weathering zones of the Mapledale Till are shown in the section at the type locality and graphically in Figure 3, section 3223. At the type section the upper part of the soil is disturbed by recent excavation. At most other localities the soil appears to be developed on colluviated material, which at a depth of 2 or 3 feet contains many flat pieces of sandstone ("channers"). The A-horizon of the soil is a light yellow-brown loam or silt loam and the B-horizon is silt loam or silty clay loam. Below the true soil is intensely weathered till (B-3 soil horizon), generally mottled, passing downward into yellow-brown, somewhat weathered till. Till of fresh appearance was not seen in any section less than 8 feet below the surface. The till is oxidized to a depth of 16 feet at the type section.

Weathered material is preserved at some places on the Mapledale Till where it underlies the later Titusville Till. At some places only the lower part of the former soil remains, but at others almost a complete weathering profile is preserved. Buried soil — paleosol — illustrated in some of the longitudinal sections shows the position and range in thickness. The relation of weathered Mapledale gravel to paleosol developed on Mapledale Till is illustrated in Figure 27. Columnar sections of the paleosol and of the weathered zones at the type locality and at localities in the valley of West Pithole Creek are shown in Figure 3. Most sections of the paleosol are truncated or decapitated, but at localities in Worth Township, Mercer County and at the Vanport quarry near Slippery Rock in Butler County, unweathered Titusville Till overlies silt which has protected the underlying paleosol from erosion (Fig. 3, sections 2382 and 3149). In these places the Mapledale Till is intensely weathered to a depth of from 7½ to 9 feet. The till is oxidized to a depth of about 10 feet.

An interesting example of contortion of weathered zones produced by colluviation of the Mapledale Till was exposed in a new road cut on a hill slope 1¼ miles southeast of Garland, Warren County (Fig. 4). At this locality some of the oxidized material has been later intensely reduced.

At many places throughout the area in which the Mapledale Till outcrops, silt, ranging in thickness from a few inches to more than 2 feet, overlies the soil derived from till. The silt is much younger in age. At a fresh cut just west of Pleasantville, Venango County, the silt is 3 feet thick and is comprised of two layers, the lower of which is much more weathered than the upper layer. This relationship is similar to that reported farther west in Ohio (White, 1967, p. 35). This silt overlying surface soil derived from Mapledale Till is correlative with the silt overlying buried paleosol illustrated in Figure 3, section 3153.

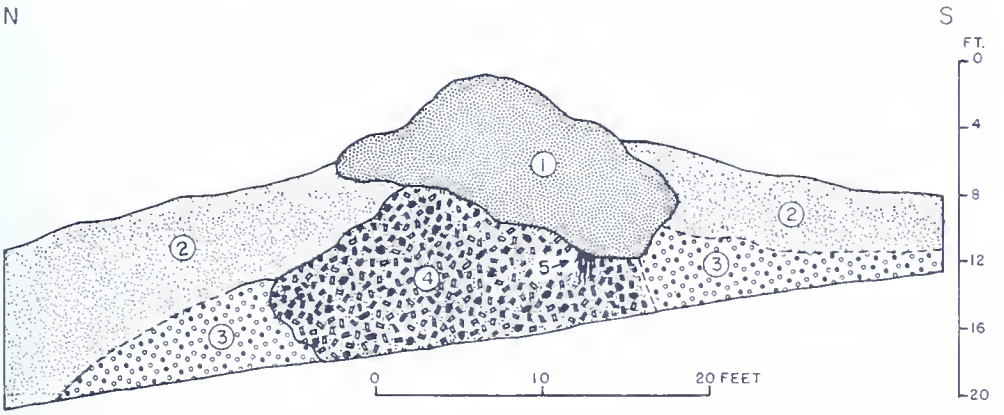

Figure 4. Sketch of glacial deposits in road cut 1¼ miles SE of Garland, Pittsfield Township, Warren County.

1. **Boulder, coarse sandstone, overhangs cut about 2 feet.**
2. **Soil and till, yellow to drab brown, very severely weathered.**
3. **Till, brown and red-brown, partly gravelly and pebbly, partly iron cemented ("plinthite").**
4. **Till, sandy-clayey, gray and blue-gray, with gray-blue ("vivianite-like") stains; pebbles of rotten sandstone and shale, 1 granite and 2 quartzite.**
5. **Small spring - 1 gal/min?**

Stratigraphic Position

The Mapledale Till is underlain at most places by bedrock, but at a few localities much weathered Slippery Rock Till is the underlying material.

In the area where the Mapledale Till is the surface drift, a layer of silt ranging from a few inches to 3 feet in thickness caps the till in some places, as already described.

West of the Titusville margin, Mapledale Till is overlain by Titusville Till. The upper part is usually weathered and at some places a thick paleosol is preserved (Fig. 3).

Surface Expression

The surface expression of the Mapledale Till, except for the few kame deposits to be described, shows no constructional aspects. The surface of the Mapledale area is that of maturely to sub-maturely dissected uplands with narrow valleys. This is a rock-controlled topography only very slightly modified by glacial deposits and presumably by earlier glacial erosion. Although the topography appears to be almost entirely erosional, the hills are a little less sharp than those to the east in the nonglaciated area.

The topography of the Mapledale Till in the subsurface, where it is buried beneath later deposits, is somewhat more irregular than the pres-

ent land surface; this irregularity is illustrated in the cross sections, Figures 17, 23, 28, 29, 30, 31. The Mapledale surface may have retained some constructional character in the area now mapped as the Kent moraine (Fig. 31).

Outwash Deposits

Outwash deposits in the form of kames or dissected kame terraces are present at several places in the area of Mapledale Till outcrop. Outwash is also present in the subsurface — buried beneath younger till. The most extensive area of outwash is in Sugar Creek Township, Venango County, north and northwest of Franklin. Two adjacent pits of the Phillips Excavating Company are located on the west side of the valley of Patchel Run, just northwest of the crossroad, 0.7 mile north of French Creek at Foster Corner and 0.9 mile west-northwest of St. Patrick's Cemetery in Oak Hall, a northern suburb of Franklin.

At the pit nearest the crossroad, 35 feet of gravel is exposed at the upper part of the pit and 20 feet at the lower part. The gravel is extremely variable in texture, ranging from bouldery to sandy. The bedding is irregular and dips at steep angles. Cobbles and pebbles are mainly sandstone, but at lower levels crystalline rocks are more common, amounting to about 5 percent of the total. Crystalline rocks in the upper 15 feet are all rotten and deeply weathered and many of those to depths of 30 feet are etched by weathering. The gravel in the upper part has a strong brown color with a mixture of secondary clay. The upper 10 feet are so weathered that the character of the original material is uncertain at places.

In the pit 100 yards north of that at the crossroads, 30 feet of weathered, coarse gravel is exposed. The gravel is very rusty colored and secondary clay is present to depths of 30 feet. Some of the iron-rich gravel resembles plinthite (Soil Survey Staff, 1960, p. 62). Ninety-four percent of the pebbles are sandstone, 4 percent quartzite, and 2 percent crystalline at a depth of 30 feet. At several places in the pit the gravel is so little washed that it resembles till. This character, as well as the irregular, steep bedding and the rapid change in texture, indicates that the material was deposited at or very close to an ice edge.

At the Vincent gravel pit, 0.3 mile east-southeast of the Phillips pits, 25 feet of rust colored, bouldery gravel containing secondary clay is exposed. Drilling indicates at least 25 feet of gravel beneath the floor of the pit.

At one place in the Phillips pit 4 feet of fresh, lighter colored, less weathered gravel and till was observed above the more weathered Mapledale gravel and at one place in the Vincent pit, 8 feet of much weathered till overlies the gravel. These are interpreted as Titusville deposits at the margin of the till sheet.

Deeply leached gravel, in which all the crystalline cobbles are etched and weathered, is exposed in a face 15 feet high at a small gravel pit just south of the road fork, 2.4 miles west of the center of Pleasantville, Oil Creek Township, Venango County.

Thirty feet of exceedingly coarse and very poorly sorted gravel is exposed in a small pit 0.2 mile west of the western limit of Youngsville and 0.2 mile north of U. S. Highway 6, Brokenstraw Township, Warren County. The gravel forms a terrace between Meade Run and Mathews Run, rising 50 feet above the lower terrace of Wisconsinan age upon which the highway and much of Youngsville are built. The gravel is oxidized and weathered to the base. Many sandstone rocks are included, the largest of which is very angular and is about 6 x 8 x 17 feet. Some siltstone slabs are present, the largest of which is 10 feet long and 1½ feet in thickness. Only rare crystallines are present. The presence of these irregular thin slabs of rock indicates a very short distance of transportation both by ice and by meltwater. Those crystalline rocks which are not quartzite are etched and rotted to at least a depth of 25 feet. This ice contact material, 1¼ miles south of the glacial boundary shown in Plate 1 of Bulletin G-32, indicates that the area of Mapledale Till should probably be extended from Pittsfield eastward past Youngsville to a point north of Gunderville, to include the area between the margin of the Titusville Till ("inner Illinoian") and Brokenstraw Creek.

Another deposit of very deeply weathered gravel, shown as a kame deposit on the map in Bulletin G-32, occurs on the west side of Andrews Run, 3 miles south of Pittsfield, Pittsfield Township, Warren County. It extends for about ¾ mile west of the junction of Rattlesnake Run with Andrews Run. To the north the material forms an irregular terrace which rises 100 feet above the valley floor. The western part of the deposit is a ridge which almost closes the valley of Birch Springs Run, forcing that stream to make a bend to the west in order to enter Andrews Run. The ridge rises 200 feet to an irregularly flat top. In this part of the deposit, the gravel is probably a thin veneer on bedrock since siltstone bedrock outcrops along ditches of a forest road at a few places.

The material, as seen in very shallow pits, road cuts, and along the road surface, is generally well rounded, coarse gravel containing some granite and quartzite pebbles and cobbles. The granites have a weathering rind up to ½ inch in thickness and some small cobbles are rotten throughout. At the north end of the deposit severely weathered till is exposed along the road. The gravel of this deposit is markedly different from the other deposits of Mapledale age in which crystalline cobbles are so rare and in which the sandstone particles are generally angular.

Only very tentative explanations of the origin of this "Andrews Run" gravel can be proposed. It may be the same age as the predominantly

sandstone gravel at Youngsville and at Franklin, but the markedly different composition does not make this seem likely. It is not believed to be a younger deposit (Titusville?), as no Titusville Till was noted eloser than 4 miles to the west, along the line at which the Titusville Till boundary is drawn.

Weathered gravel composed mainly of sandstone eobbles and lying beneath calcareous Titusville Till (Fig. 32) in the upper part of the excavation at the north end of the Shenango Dam at Sharpsville, Mercer County, is interpreted as Mapledale in age.

At least some of the weathered gravel under unweathered till in the Little Beaver River Valley in Big Beaver, Darlington Township, Beaver County, near New Galilee, is of Mapledale age. The buried weathered gravel exposed in a strip mine (Fig. 33) 1 mile southeast of Enon Valley appears to be a kame terrace deposit of Mapledale age, and the lower gravel exposed in a strip mine 1 mile north of New Galilee is in the form of buried kames, as shown in Figure 28. In this section, it is interesting to note that younger buried kames also oceur, separated from those of Mapledale age by fresh Titusville Till.

Sitler (1957, p. 88, 101) noted the possibility that some of the gravel in this area near New Galilee "may represent older deposits." In Bulletin G-32 (p. 29-30) it was noted that these deposits near New Galilee were "apparently anomalous in their relationship to" older or younger drift. The availability of new exposures now shows that the gravel is of several ages. The lowest gravel is Mapledale (Fig. 28). Some other buried gravel is Titusville and some gravel of Kent age oecurs at the surfaee. A clear, extensive exposure, such as that in the strip mine 1 mile north of New Galilee, is required to show the relationships of the different ages of gravel.

Deeply weathered gravel at high elevations is reported from the Allegheny and Ohio valley in Pennsylvania by Leverett (1934, p. 98-100), and in the Ohio valley downstream from Pennsylvania by Lessig (1961). The relation of these small high remnants of valley train deposits to the early tills remains to be worked out. It is possible that some of the lower terraees referred to as "Illinoian" by various writers, may be related to the Titusville ice advance and thus be early Wisconsinan rather than Illinoian.

Age and Correlation

The age and correlation of the Mapledale Till can only be tentative. Its stratigraphic position below the Titusville Till of Altonian (early Wisconsinan) age and the presenee of thiek paleosol indicate that it is older than Wisconsinan. The deep weathering of the material where it forms the surface drift further supports a pre-Wisconsinan age assignment. Although it is probably of Illinoian age, it eannot be traced into

drift of known Illinoian age and therefore its preferred designation is "Illinoian (?)".

The Mapledale Till is correlated with the material in extreme southeastern Chautauqua County, New York, just north of Warren County, Pennsylvania, described as "attenuated drift" by Muller, (1963, p. 37, pl. 1).

The Mapledale Till has been traced westward into the eastern margin of Ohio. Till and gravel lying beneath drift of "early Wisconsinan" age have been described in Portage County (Winslow and White, 1966, p. 20), Stark County (White, 1963, p. 126), Wayne County (White, 1967, p. 12), and Cuyahoga County (White, 1953a, p. 36), but the relationship of the Mapledale Till to any of these Ohio units has not yet been established.

TITUSVILLE TILL

The name Titusville Till has been proposed (White and Totten, 1965) for the till formerly called "inner Illinoian" (Shepps and others, 1959, p. 21). The type section, near Titusville, is that earlier measured and described by Droste and Tharin (1958, p. 62) from a fresh cut in an excavation for relocation of Pennsylvania Highway 8, 1.6 miles south of the post office in Titusville and 1.2 miles southwest of the Drake Oil Well. The section which follows was described and sampled in detail in order to study the sequence of alteration in the clay minerals:

Type Section of the Titusville Till

	Unit Thickness Ft.	In.	*Aggregate Thickness* Ft.	In.
Wisconsinan (Altonian):				
Titusville Till:				
Zone I				
Loam, silty, gray brown; A-1 soil	0	9	0	9
Loam, silty, dark dusky yellow; A-2 soil	0	7	1	4
Loam, silty, elayey, moderate orange and gray mottling, small weathered siltstone and shale pebbles; upper B-1 soil	0	6	1	10
Loam, silty, elayey, pronouneed orange and gray mottling, nusiform fraeture, small weathered sandstone, siltstone, and shale fragments; middle B-1 soil	1	7	3	5
Loam, silty, elayey, pronounced orange and gray mottling, compaet with some prismatie strueture, well-weathered erystalline roeks, sandstone, siltstone, and shale fragments	1	0	4	5
Zone II				
Till, silty, elayey, thoroughly weathered orange and gray stains in joints, manganese stain coating joint surfaees, weathered erystalline roeks, siltstone, and shales	1	11	6	4

	Unit Thickness Ft.	In.	Aggregate Thickness Ft.	In.
Zone III				
Till, as below but not calcareous	2	3	8	7
Zone IV				
Till, silty, moderately pebbly, calcareous, moderate yellow brown to olive brown, rough horizontal fracture; till matrix is slightly calcareous, but many small carbonate pebbles react violently to acid. Coal fragments common in places	7	4	15	11
Zone V				
Till, as above but light olive gray; many joints are present, along which ground water has oxidized the gray till in zones varying in thickness from 1/16 inch to 1½ inches	8	6	24	5
Sand and gravel, brown, calcareous, uneven contact with superjacent unit	7	6	31	11

Location and Extent

The Titusville Till is the surface material in a belt ranging from a fraction of a mile to 10 miles wide that extends across northern and western Warren County, extreme southeastern Crawford County, northwestern Venango County, northwestern Butler County, southern Lawrence County, and northwestern Beaver County. Its extent is shown on Figure 2 and in detail as the area of outcrop of "inner Illinoian" drift on Plate 1, Bulletin G-32. Its extent in Crawford County is well shown by Bacon and others, (1954, p. 49 and map) as the area of Titusville soil which is derived from this till. The Mapledale Till occurs beyond the eastern boundary of the Titusville Till and its western boundary is the eastern margin of the Kent Till. The Titusville Till extends far to the west below the Kent Till. The locations where Titusville Till was identified and sampled underneath younger material are shown on Figure 12. In addition to these locations, Titusville Till is present below younger drift at many other localities that are not shown on the map because samples were not collected for analysis. This till is present throughout northwestern Pennsylvania and extends farther west into Ohio.

In the area where the Titusville Till is the surface material, the thickness ranges from such a small amount that all the till is incorporated in the present soil to a thickness of 24 feet at the type section. It may be thicker at places not now exposed. West of the belt where Titusville Till is at the surface, thicknesses range from only a few feet to more than 75 feet. In a strip mine 1¾ miles south of Moravia, North Beaver Township, Lawrence County, Titusville Till appeared to be more than 75 feet thick, but slumping prevented precise determination. It was reported that ¼ mile to the north till more than 150 feet in thickness cuts out coal in an (now abandoned) underground mine. Over 300 feet of drift

is reported just to the north (DeWolf, 1929, p. 28), but the lowest part is undoubtedly pre-Titusville. It should be emphasized that throughout most of northwestern Pennsylvania the bulk of the drift is Titusville Till.

Another very thick section of the Titusville Till is along the road on the west side of French Creek, 1.6 miles south of Venango, Venango Township, Crawford County. This section, with a total thickness of drift of about 100 feet, was described and figured in Bulletin G-32 (p. 14-19) and Shepps (1955). When first discovered by Shepps in 1953, the lower part of the section was clean and clear and quite accessible, but the upper part was very steep and could not be examined in close detail. The upper 30 feet was assigned to the Kent ("early Cary"). New road cuts in the vicinity now reveal that the Kent Till is only from 3 to 8 feet in thickness in this whole area, with Titusville Till underlying it. Re-examination of the top of the Venango section, in detail now made possible by greater erosion, shows that the Kent Till is only 3 or 4 feet thick and that all the drift beneath is Titusville to a depth of 75 feet below the surface. At least three separate layers of Titusville Till are identifiable, with sand between each of them. The lower part of the Venango section, composed of pre-Titusville drift, is now covered by slumped material and a restudy of this part is impossible.

Composition

The unaltered Titusville Till is olive gray. The oxidized till is olive brown (2.5Y 4/4). It is characterized by heavy manganese staining along the joints in the oxidized part and by conspicuous stains at the contact between the pebbles and the matrix. It is much harder than the overlying Kent Till.

The mean texture of the matrix of the Titusville Till is 45.4 percent sand, 36.9 percent silt, and 17.7 percent clay. The range is 30 to 60 percent sand, 12 to 58 percent silt, and 9 to 30 percent clay. The sand increases at a rate of 0.33 percent per mile in a general southeast direction and the clay increases in the same general direction at a rate of 0.08 percent per mile.

The feldspar content of the Titusville Till ranges from 4 to 38 percent with a mean of 12 percent. The feldspar content is lowest along the margin of the till and increases away from the till margin in a general northwest direction at the rate of 0.41 percent per mile. The details of the mineral variation will be discussed in another section.

The mean carbonate content of Titusville Till is 2.4 percent, about evenly divided between calcite and dolomite. It reacts visibly to hydrochloric acid.

Anomalous "Red Till"

At several places in northwestern Pennsylvania and at places in Ohio (White, 1967, Fig. 5) streaks from a small fraction of an inch to 2 inches in thickness (but generally less than 1 inch) of a distinctive red or maroon clayey till were observed in the upper part of the Titusville Till. Two greater thicknesses of this till were observed in the course of this investigation. In an exposure in a strip mine 2 miles southeast of Grove City a layer of maroon till (recorded in field notes as "purple-pink") had a maximum thickness of 2 feet (Fig. 17, unit 5). An irregular mass of red till, at least 5 x 10 feet was observed 3 miles south of Cambridge Springs, where the relations illustrated in Figure 5 were displayed. Contrast with the surrounding Titusville Till was sharp. This "red till" is distinctly clayey, containing fine pebbles. It is exceedingly calcareous and its color on the Munsell scale is dark reddish brown (5YR 3/3).

The "red till" resembles the Bécancour Till of the Bécancour Valley in Quebec, whose origin is obvious because it owes its "rich red color" to the Queenston shale of Ordovician age (Gadd, 1960, p. 8). Inclusions of till of strikingly different color from enclosing material in east-central North Dakota are reported by Kelly and Baker (1966). They describe "orange zones within normally buff-colored till" and state that "most exposures of the orange till do not exceed one square foot."

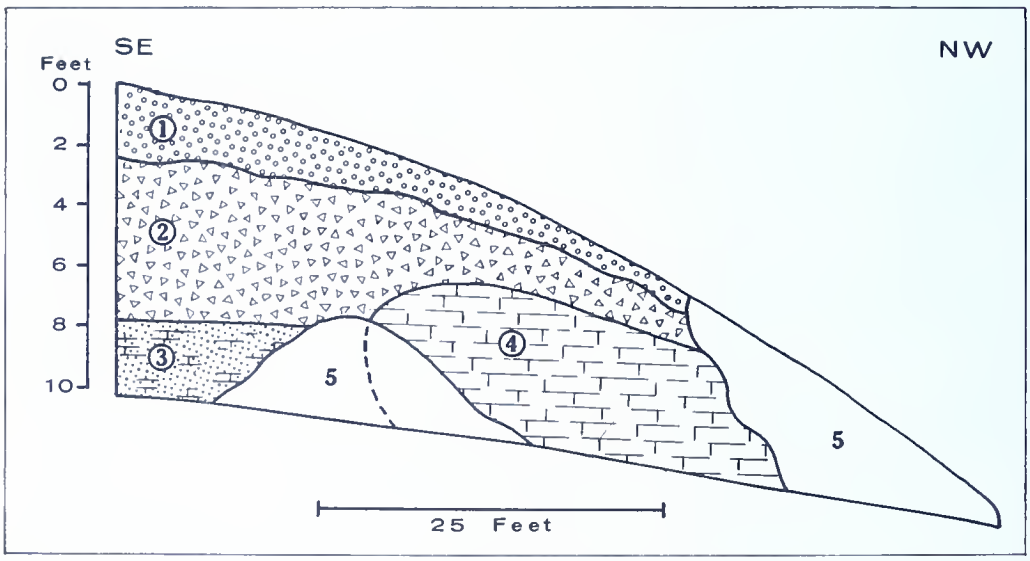

Figure 5. Sketch of "red till" inclusion in Titusville Till, exposed in road cut 3 miles S of Cambridge Springs, Rockdale Twp., Crawford Co.

1. **Gravel, weathered.**
2. **Till, olive-brown, leached; TITUSVILLE.**
3. **Till, sandy, olive-brown, calcareous; TITUSVILLE, (2409).**
4. **Till, maroon, clayey, very calcareous, "red till" (2410, 2411).**
5. **Covered.**

The origin of the layers and masses of red till in northwestern Pennsylvania is unknown. It is not a transported mass of red calcareous shale because it has glacial pebbles included in it. No separate unit of red till has ever been observed in the Allegheny Plateau in Pennsylvania or Ohio. It is not transported weathered material, as not only is intense red color not known in weathered tills in the plateau, but also the material is very fresh and very calcareous, and hence has not been weathered.

Weathering Character

The weathering zones of the Titusville are described in the type section above and the clay mineral changes have been discussed in detail by Droste and Tharin (1958). The depth of leaching is generally about 10 feet and at the type section the depth of oxidation is 15 feet 3 inches. Those weathering profiles found that extended to calcareous material, in the area where Titusville Till is at the surface, are illustrated in Figure 6.

Truncated weathering profiles on Titusville Till are present in some places where younger till overlies the Titusville. No complete paleosol has been discovered because at almost all exposures the upper part has not been preserved. At a few places, that part of the paleosol preserved is a very hard, dark-reddish-brown clay loam, the lower part of which contains many fragments of angular sandstone and siltstone ("channers") as much as 3 inches in length. Shepps (1955, p. 42) considered that some of this material noted near the state line was formed by periglacial action. Farther west, in Ohio, similar material on the Millbrook Till, a correlative of the Titusville Till, has been ascribed to translocation and "pedisediment action" (White, 1967, p. 21).

Stratigraphic Position

The Titusville Till is underlain either by weathered Mapledale Till or by bedrock, as illustrated in many of the diagrams. West of the Kent margin, Titusville Till is overlain by Kent Till, but at some places in northwestern Mercer County, northern Crawford County, and southern Erie County, Kent Till may be missing and Lavery Till may lie directly upon the Titusville Till (Fig. 8, 2623, 3179). At some places sand or gravel separates Titusville Till from the overlying Kent Till. Unusual thicknesses of gravel, as much as 20 feet, occur at several places in the Grove City area and are shown in Figures 19 and 34.

Divisions

The Titusville Till, in the area where it is at the surface, appears to consist of a single sheet, except for the possible indication of a second lower till sheet at the peat locality to be described. West of the outcrop area the Titusville Till consists of from 2 to 5 units, informally designated in the diagrams as "Titusville I," "Titusville II," and so on. The units are

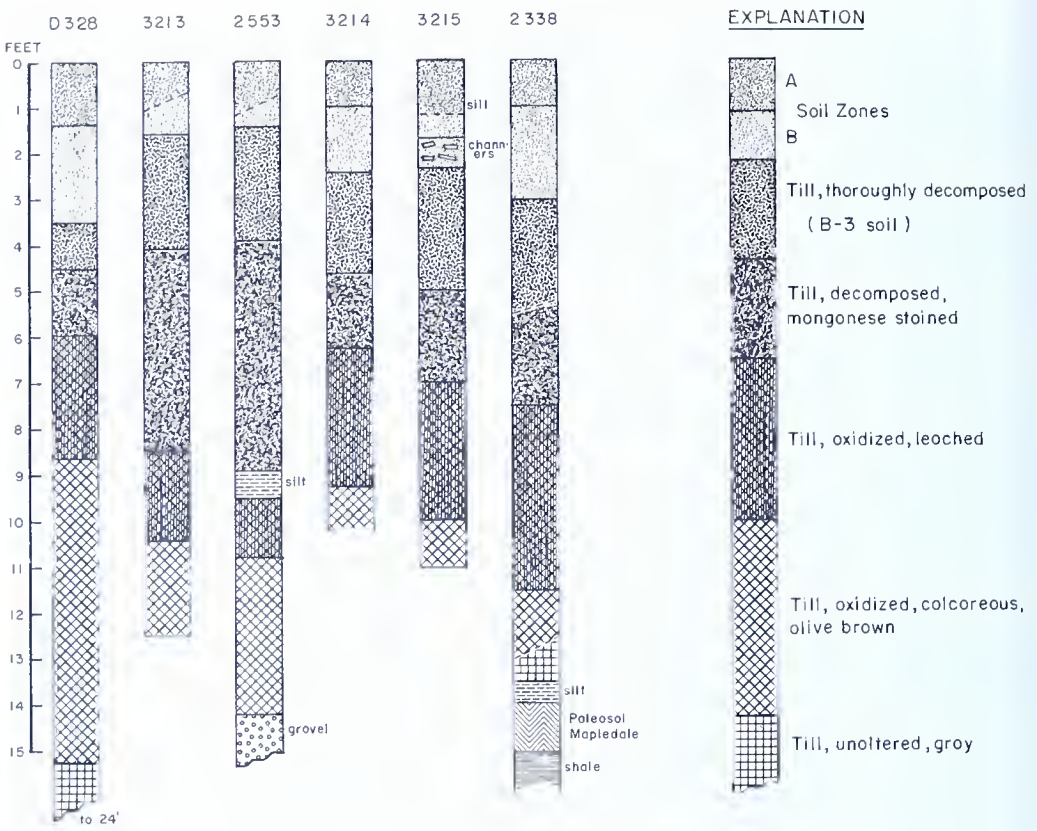

Figure 6. Columnar sections of weathering horizons of Titusville Till.

D328 Type section. Road cut 1.6 miles S of Post Office in Titusville.

3212 Borrow pit 100 yards NE of type section.

2553 Strawbridge gravel pit .6 mile S of East Titusville.

3214 Road cut and auger boring 1 mile E of Wallaceville, Plum Twp., Venango Co.

3215 Road cut and auger boring 1 mile S of Grand Valley, Eldred Twp., Warren Co.

2338 Strip mine 1¾ miles E of Harrisville, Marion Twp., Butler Co.

separated in most places by sand and gravel, sometimes of considerable thickness. The most continuous layer of sand and gravel is below the uppermost Titusville sheet and ranges in thickness from a few inches to as much as 20 feet. The increase in thickness appears generally to be upward, in constructional forms, rather than downward in channels. The thicker gravel gives the appearance of buried kames (Fig. 35, 36). A series of such buried kames was well exposed in a strip mine near Filers Corners, Lake Township, Mercer County, one of which is illustrated in Figure 27. A more uniform, sheetlike, thinner deposit below the uppermost Titusville Till sheet is illustrated in Figure 26. A sheetlike deposit which expands in a channel is shown in Figure 37. The

gravel at Titusville that underlies the till at the type locality and at the gravel pits east and south of the city, may be correlative with gravel below one of the lower sheets of Titusville Till. Measured sections to show the divisions of the Titusville Till are given in the Appendix.

The presence of sand and gravel below the upper till sheets is so general in much of Mercer County and Lawrence County that it is taken into consideration in strip mining, as this layer may be water-bearing and thus the stability of cuts is reduced. In some strip mines it is the practice to remove the overburden in two lifts, the first taking off the material above the sand and gravel, the material below being removed later. In some mines where this has not been done, extensive masses of till over the sand and gravel have slumped onto the floor of the pit, covering the coal bed which was ready for removal. In deeper cuts for highway construction this sand or gravel layer is evident as a "wet zone" along the slope and may require special treatment to prevent slumping. The divisions of the Titusville Till are indicated not only by the presence of the sand and gravel layers, but also by a change in color from olive gray (5Y 4/2) to a more "bright" gray (5Y 3/1). These divisions stand out sharply on the face of many excavations.

The textural differences among the Titusville Till sheets are not great, and the results from laboratory studies of scores of samples do not permit characterization of the different till sheets on the basis of texture.

Differences in feldspar content and composition among the different Titusville Till sheets in Pennsylvania have been studied, but further, more detailed sampling and statistical analyses are necessary for meaningful statements (Gross, 1967). Just west of Pennsylvania, south of Youngstown, Ohio, a detailed study of the divisions of the Titusville Till has recently been made by Moran (1967), where divisions of the Titusville Till were obvious in miles of quarry walls. On the basis of varying feldspar content, Moran divided the Titusville Till into five divisions, although at no place did all five occur in one section. The sheets overlapped, the upper ones extending less far south than the lower ones, indicating deposition by pulsations of an ice sheet, each one reaching less far south than the earlier ones.

Inasmuch as the Titusville Till in Pennsylvania appears to be composed of a single sheet in most of the area where that till is at the surface, but of two or more sheets in the subsurface to the west and northwest, the various Titusville Till sheets in Pennsylvania are interpreted as a result of deposition by ice which readvanced several times, but with each readvance reaching less far than the earlier ones. The Kent moraine is believed to be the zone along which the later Titusville Till sheets "stacked up" to form the major volume of this feature.

Surface Character

The topography of the Titusville Till in the area in which it forms the surface material is, in general, an erosional or masked erosional topography. Aside from the gravel deposits near Titusville and several kames in Venango County, the surface exhibits only very little constructional aspect. Nevertheless, the surface is less erosional in appearance than that of the Mapledale area, a character which is most obvious from an airplane flying at a high elevation.

The surfaee of the Titusville Till, where it is buried below later drift, to a great extent mirrors the present surface. The bulk of the Kent moraine (Fig. 2), whose surface extent in detail is shown on the map of Bulletin G-32, is aetually Titusville Till made up of several till sheets deposited by separate pulsations. Over this constructional surface is draped a layer, generally only a few feet thick, of Kent Till with some kames of Kent gravel eontributing to the irregularity of the surface.

Kames associated with the Titusville Till exist at various places in the area of outcrop. Several of these are present in Mineral Township, Venango County, and others are present in Oil Creek Township, as shown on the map in Bulletin G-32. The largest area of gravel of Titusville age is in the valley of Oil Creek, east of Titusville, where gravel more than 50 feet thick is banked along the valley sides in the form of kame terraees.

Age

The age of the Titusville Till is determined from C^{14} analysis of peat discovered by Mr. Lewis C. Strawbridge in a test pit 300 yards west of his large gravel pit, ½ mile southeast of Titusville, in the eastern part of the large kame terraee whieh extends for nearly a mile on the south side of the valley of Pine Creek eastward from its junction with Oil Creek. The loeation is 0.3 mile east of the southeast corner of the Titusville corporation line and 0.9 mile east-northeast of the famous Drake Oil Well. In the late spring of 1964, Mr. Strawbridge's exploration disclosed a layer of peat 1 foot in thiekness after which the test pit was filled. Carbon 14 assay of a fragment of this peat, whieh has been preserved by Mr. Strawbridge, gave its age as 31,400 ± 2,100 years (I-1465, White and Totten, 1965). In 1965, Mr. Strawbridge re-exeavated the deposit to a greater depth, thus exposing more than one layer of peat. A sample of the uppermost peat colleeted directly from this exeavation has a C^{14} date of 39,900 + 4,900 — 2,900 years (I-1845). This date is regarded as more aecurate than the first one, as the 1964 sample did have some opportunity for contamination. A lower layer of peat, separated from the upper peat by 3 feet of gravel and till-like material has a C^{14} age of 40,500 ± 1,000 years (GrN-4996).

In 1967, Mr. Strawbridge again excavated the deposit, at this time cutting 10 feet or more farther into the face, exposing a total width of some 50 feet, and cutting a ditch for drainage. A section measured at this latest excavation is as follows:

Section of Till, Gravel, and Peat Layers in the Strawbridge Pit

	Unit Thickness Ft.	In.	*Aggregate Thickness* Ft.	In. (*of peat containing layers*)
Wisconsinan:				
Titusville Till:				
(Till, olive-brown, calcareous, overlies gravel in upper part of terrace 200 yds. south)				
Gravel, yellow-brown, coarse to medium	20	0		
Gravel, yellow to orange-yellow	3	0		
Gravel, sandy, orange	0	1		
Unconformity, with relief of 6 inches				
Peat, irregular at top, brown, with gray, silty sand intermixed	0	4	0	4
Peat, black, position of 1965 sample I-1845, 39,900 + 4,900 — 2,900 yrs. B.P.; 1967 sample OWU 315, 35,000 + 1,835 — 2,385 B.P.	0	8	1	0
Sand, gray	0	5	1	5
Peat, irregular (3305)	0	3	1	8
Sand, fine gravel, and till-like material, gray	1	9	3	5
Peat, black, irregular, layer (disturbed)	0	1	3	6
Silt, gray, sandy	0	6	4	0
Peat, brown and black, fibrous (moss peat?) position of 1965 sample GrN-4996, 40,500 ± 1,000 yrs. B.P.; 1967 sample OWU 316, > 37,500 yrs. B.P.	0	7	4	7
Sand and gravel, gray	1	6	6	1
Peat, macerated, in ½ inch to 1 inch layers in gray sand (3306)	0	3	6	4
Sand, coarse, gray	0	6	6	10
Water level				

Samples collected in 1967 were submitted to the Ohio Wesleyan University radiocarbon laboratory for additional C^{14} analysis, with the results shown. A study of the pollen in the various peat layers is being made by Mr. Albert Berti of the University of Western Ontario.

We are, as yet, unable to determine which Titusville Till sheet (or sheets) found in the subsurface is represented at Titusville, but it is probable that the upper till sheets buried in the Kent moraine are somewhat younger than the till at Titusville, but not markedly so, as no buried weathered zone has been observed on any but the uppermost Titusville Till sheet in the exposures seen.

Correlation

The Titusville Till is correlated with the Mogadore Till of the Akron, Ohio, region (White, 1960, p. A-3) and with the Millbrook Till

of the Killbuck glacial lobe in northeast-central Ohio (White, 1961; 1963, p. 138; 1967, p. 9, 18). It appears to be about the same age as the upper part of the Winnebago drift of northern Illinois (Frye and Willman, 1960, p. 2) and the Southwold drift of Ontario (Dreimanis, 1964, p. 150). The Titusville Till may be related to the lower of two upper tills at Otto, New York, about 65 miles northeast of Titusville (Muller, 1964, p. 465, unit 7). One of the lower units of the Titusville Till may be correlated with the Gahanna Till near Columbus, Ohio, (Goldthwait and Forsyth, 1965, p. 77).

KENT TILL

Type Locality

The Kent Till is named for the city of Kent in western Portage County, Ohio (White, 1960, p. A-5). It has been followed by continuous tracing from the type locality in Portage County across eastern Ohio and across western Pennsylvania to New York.

Location and Extent

The Kent Till in northwestern Pennsylvania extends southwest in a belt west and northwest of the outcrop area of Titusville Till from New York (Muller, 1963, p. 39) across northern Warren County, southeast Erie County, much of Crawford County, much of Mercer County, and almost all of Lawrence County, thence passing into Ohio. The Kent Till extends northward and northwestward below the Lavery Till and has been traced below this till northward into Erie County.

The northwestern part of the area of Kent Till shown on the map in Bulletin G-32 is now known at some places to have upon it a very thin and discontinuous deposit of a later till identified as Lavery. The tentative margin of this thin and discontinuous material is indicated on Figure 2 and will be discussed in the section on Lavery Till. In this belt the Kent Till is actually the surface material in much of the area.

The Kent Till is almost everywhere thin; at many places it is less than 5 feet in thickness and is rarely more than 10 feet. It was earlier thought (Shepps and others, 1959) that the Kent Till was many tens of feet in thickness, especially in the area of the Kent moraine, but the present investigation, having the advantage of many new exposures of great extent, shows that the Titusville Till is so close to the surface that at many places leaching has penetrated the thin Kent Till and advanced into the underlying Titusville Till, so that the weathered upper part of the drift is composed of two different tills. This accounts for the extreme variation in depth of leaching reported earlier (Shepps and others, 1959, p. 32); the greater depths of leaching are actually a combination of completely leached Kent Till overlying a variable thickness of leached

Titusville Till. Many of the sketches of sections show the continuity, but small thickness of the Kent Till.

The identification as Kent of weathered and leached till only 4 feet or even less in thickness is confirmed at many places by following a continuous outcrop to a place where the till becomes thicker than 5 or 6 feet, where it is then calcareous and may overlie leached Titusville Till. In favorable places, the thickness may increase to 10 feet or more and here the Kent Till is not only calcareous, but gray, because it is unoxidized. In such situations (Figs. 17, 24, and 31), the gray Kent Till, overlying oxidized, olive-brown Titusville Till is strikingly shown to be a different and much later deposit from the underlying material.

Composition

The unaltered Kent Till is exposed in only a few places, because, in general, the till is so thin that it is oxidized throughout. Unaltered Kent Till is exposed in a strip mine 2 miles east of Grove City (Fig. 34) and in a strip mine 2 miles northwest of Raymilton, Sandy Lake Township, Mercer County (Fig. 24). The unaltered till is gray (5Y 3/2). The Kent Till is a coarse, sandy till containing many pebbles and occasional cobbles and boulders. The mean texture of the Kent Till is 43 percent sand, 38.5 percent silt, and 18.5 percent clay. However, the texture is quite variable, departing somewhat widely from the mean. It becomes more sandy toward the margin, as will be discussed in a later section.

The feldspar content of the Kent Till ranges from 4 to 33 percent with a mean of 13 percent. However, the variation is primarily an areal one, ranging from less than 10 percent along the outer margin of the till to more than 20 percent 20 or 25 miles within the margin. This increase in feldspar content with distance from the margin is shown in Figure 14 where the feldspar content of 22 samples is recorded and isopleths are constructed. Statistical studies of this variation will be discussed later.

The mean carbonate content of the Kent Till is 3.2 percent. It effervesces vigorously with HCl.

Weathering Character

The till is oxidized to a depth of about 10 feet. The oxidized Kent Till is yellow-brown (10YR 4/4) in contrast to the olive-brown (2.5Y 4/4) oxidized Titusville Till. This difference in color of the oxidized till and less compact character of the Kent Till in comparison to the Titusville is reliable criteria for distinguishing the two tills.

The Kent Till is leached of carbonates to a depth ranging from 60 to 80 inches, but at most places is leached about 70 inches. Because it is so thin, leaching extends in many places through the Kent Till and the upper part of the underlying Titusville Till may also be leached. The depth of strong weathering and soil formation is about 40 inches, below

which the till is not so much weathered, but preserves a till-like character. Below this zone the till is fresh in appearance, but noncalcareous. These weathering zones are similar to those described in detail for the Kent Till in Ohio (White, 1963, p. 132-134).

At some places where the Kent Till is overlain by Lavery Till, weathered material is preserved in the upper part of the Kent Till, as shown in Figures 41 and 43. At some places underneath the Lavery Till the upper few inches to 1 foot of Kent Till is a disturbed, somewhat weathered zone with angular, flat, sandstones and siltstone pieces ("channers"), as shown in Figure 8. This zone is ascribed to colluvial action.

Stratigraphic Position

The Kent Till is underlain by Titusville Till. At places the weathered surface of the Titusville Till is preserved beneath unweathered Kent Till. Where the Kent Till is very thin and leached throughout, and the underlying Titusville is also leached, the distinction between the two tills is not always easy. They can be distinguished from each other on the basis of the yellow-brown (10YR 4/4) color of the Kent Till and the olive-brown (2.5Y 4/4) color of the underlying Titusville Till. The Titusville Till is harder and dark stains along joints are more prominent. At most places the difference in hardness is so appreciable that the "number of blows per foot" required for penetration by the pick in clearing off an outcrop is very much larger in the underlying Titusville Till.

At some localities a layer of sand or silt is present between the Kent Till and the underlying Titusville Till and at some places this may have a thickness of 20 feet or more as will be discussed below.

The Kent Till is overlain by the Lavery Till. As already noted the overlying material is thin and discontinuous in southeastern Erie County, in northern and eastern Crawford County, and in northwestern Mercer County, but is much thicker farther north in the area of the Lavery moraine (Bulletin G-32, map).

Surface Expression

The topographic form of the Kent Till where it is the surface material has been described in Bulletin G-32, p. 32-34, and the differentiation between ground moraine and moraine is shown in detail on the map accompanying that report. The most striking topographic feature associated with the Kent drift is the Kent moraine, which extends from southwest to northeast along the margin or a mile or so back from the margin of Kent Till. This moraine ranges in width from less than 2 miles to almost 10 miles, and can be traced from its type locality at Kent, Ohio, into Pennsylvania, and thence into New York State (Muller, 1963, p. 40). It must be emphasized, however, that the constructional forms, including the Kent moraine, are not due, in most places, to increased thickness of

Kent Till. The Kent Till is, in general, no thicker in the Kent moraine than in the Kent ground moraine. It is the thickening of the underlying material, mainly the Titusville Till, which gives rise to the more constructional features of the Kent moraine. Sitler (1957, p. 16) suggested that the Kent moraine near Portersville overlies older drift with buried constructional topography. As more and more extensive outcrops in superhighway construction and in quarries and strip mines become available, it is increasingly evident that many end moraines are compound features which do not owe their topographic form to the last ice sheet to cover them nor to the surface till of the moraine (White, 1960).

At places the Kent Till, rather than accentuating, has reduced the relief of underlying morainic topography. When seen in extensive outcrops in deep strip mines the appearance of this buried morainic topography is very striking. Examples are illustrated in Figures 27 and 30.

Outwash

The valleys within the areas of Kent drift contain extensive kame terraces of sand and gravel. Areas of kames are present in the Kent moraine. These are shown in detail in the map of Bulletin G-32 and are described on pages 34 to 36 in the text. Some of the gravel is of Kent age and some is of earlier age, covered by thin Kent Till (Fig. 38).

Kent gravel is known in the subsurface at several localities. Its age can be determined as post-Titusville where it overlies weathered Titusville drift. Some of these deposits appear to be buried proglacial deposits of kamelike character illustrated in Figures 34 and 39, and others appear to be more sheetlike deposits, as shown by that at Barkeyville in Figure 24. At other places, pro-Kent gravel, known to be post-Titusville because of its relation to underlying weathered Titusville Till, exists in channels ranging from a few feet to as much as 40 feet in depth. The most striking of these was seen in the Ambrosia strip mine just east of the airport south of Grove City, where a channel sloping steeply to the west has been encountered in the mining operation. When first encountered it was only an extension downward of a few feet of sheetlike gravel deposit, but within 200 yards the channel was 40 feet in depth and filled with sand and gravel (Figs. 18, 19, and 20).

The buried Kent sand and gravel was of such extent at Barkeyville and at the pit near Grove City that it was used for road construction. The presence of such buried sand and gravel deposits in excavations may present engineering problems because of the difference in stability of sand and gravel compared to that of adjacent till or bedrock. If the gravel is waterbearing, additional problems are presented; in excavations and in highway cuts where slopes are to be maintained, special attention has to be given to such situations.

Age

No organic material has been found in the Kent Till in Pennsylvania, and therefore no age based on C^{14} analysis is available. The Kent Till was thought to have a minimum age of 14,000 years (Droste, Rubin, and White, 1960), but it now appears that this is probably the minimum age for Lavery Till, which overlies the Kent Till, as will be discussed below. Wood associated with lacustrine material near Cleveland, Ohio, has a C^{14} age of about 24,000 years (W-71, 24,600 ± 800; K-361-4, 23,313 ± 391; White, 1965, p. 88; 1968). This lacustrine material in which the wood was found is now known to be associated with Kent Till and is believed to be pro-Kent. The Kent Till, therefore, is now believed to have an age of a little more than 23,000 years.

Correlation

The Kent Till is correlated with the Navarre Till of the Killbuck lobe in Ohio (White, 1963, p. 122; 1967, p. 23). The Kent Till was earlier designated as "early Cary" (White, 1953b; Shepps, 1955, p. 20,58) and believed to be the same age as the Cary drift of northern Illinois. However, as this unit cannot be traced into the area of Cary drift in Illinois, this name will no longer be used in connection with the Kent Till, or with its correlative, the Navarre Till (White, 1963, p. 122; 1967, p. 9). The Kent Till and its correlative, the Navarre Till, are now classified as "Woodfordian" in age in the classification for the Illinois glacial lobe by Frye and Willman (1960, p. 2).

The Kent Till, with a probable age of about 23,000 to 24,000 years, is correlative with the Catfish Creek Till of Ontario (Dreimanis, 1964, p. 150) and is very closely related in time to the Shelbyville Till of early Woodfordian age in Illinois (Frye and Willman, 1960, p. 2).

LAVERY TILL

Type Locality

The Lavery Till and Lavery moraine were named by Shepps (1955, p. 62, 68; Shepps and others, 1959, p. 38-40) from the type locality at the hamlet of Lavery, Erie County, 4½ miles west of Edinboro.

Location and Extent

Lavery Till in its thick phase extends in a narrow belt from New York State southwest across Erie County to northwestern Crawford County and thence into Ohio (Fig. 2). This is the belt shown in Bulletin G-32 as "Lavery end moraine" and as "Lavery ground moraine." The present investigation shows that the Lavery Till extends as much as 15 miles beyond this belt in a generally thin and discontinuous deposit, which at many places does not conceal the underlying Kent Till. In this belt it may be absent, or may be so thin that auger borings for calcareous

till may go through the Lavery Till and into the underlying Kent Till, so that samples collected by boring may be Kent rather than Lavery. This investigation did not include detailed surface studies of any of the tills, especially of the later ones. Some of the localities in which Lavery Till was noted beyond the previously mapped Lavery area are recorded on Figure 2. A line at or beyond the outermost outcrops has been drawn to show a very approximate outer boundary of the "thin Lavery Till."

This wide belt of thin and discontinuous Lavery Till continues southeastward into Ohio. Its margin passes northeastward into New York and very closely meets the line shown by Muller (1963, pl. 1) as "inferred border of ice sheet," just west of Clymer, New York, which thence extends irregularly to the northeast and east of Clymer in Chautauqua County, New York. This line is marked by the Clymer moraine (Muller, 1963, p. 42) in New York. Southwest, in Pennsylvania, patches of end moraine, called "Clymer" in Bulletin G-32, Figure 4, are just within the outer margin of thin Lavery Till. The present authors interpret the areas of Clymer moraine in Pennsylvania as material of pre-Lavery age, but with a thin veneer of Lavery Till. Discontinuous areas of Wadsworth and Rittman soils have been mapped in the region of thin Lavery Till in southwestern Crawford County (Bacon and others, 1954, p. 53 and map). These soils are typically developed in Ohio on Lavery Till and its correlative, the Hayesville Till (White, 1963, p. 135, 147; 1967, p. 25). The presence of these soils is another indication of the southward extension of Lavery Till in Pennsylvania beyond the Lavery moraine.

It should be noted that Shepps (1955, p. 73) recorded fine-grained brown till similar to Lavery Till far beyond the Lavery moraine at several outcrops in the Pymatuning Creek valley, in Pymatuning Township, Mercer County, and thought this might be the deposit of an ice lobe coming from the northwest in Ohio down the Pymatuning Creek valley. He suggested that "a detailed investigation of the Pymatuning Creek valley [in Ohio] is required to confirm or disprove the lobate advance" of later ice. This advance is now confirmed, but is was more widespread than that of a narrow lobe confined to the Pymatuning valley.

The Lavery Till is 10 feet or more in thickness in the previously mapped "thick till" area, and at some places is thick enough to preserve unweathered, unoxidized gray Lavery Till. In the area of thin Lavery Till, south of that previously mapped, the till may be totally absent, or may range from a thickness of 5 or 6 feet to material so thin that it is entirely incorporated in the present soil.

Composition

The Lavery Till has been described in detail in Bulletin G-32 and by Tharin (1958, p. 28). It is a light gray, moderately to sparingly pebbly, calcareous, silty till. The average composition of 15 samples collected in

the present study is 33 percent sand, 47 percent silt, and 20 percent clay. This corresponds very closely to the average of 20 analyses reported by Tharin (1958, p. 28). It is higher in carbonate than any of the older tills, generally containing over 10 percent carbonate.

The feldspar content of the Lavery Till is higher than any of the older tills, ranging from 16 to 40 percent with an 11 sample mean of 31 percent. There is some indication from the distribution shown in Figure 11 that the feldspar content decreases toward the margin of the drift, as is the case with other tills investigated. So few Lavery samples are available, however, that no firm statement can be made about lateral variation.

Weathering Character

In the area of thin Lavery Till at only one place was the till of sufficient thickness for the preservation of unweathered, unoxidized gray till. At all other places, the till is oxidized and generally is so thin that it is more or less severely weathered. The oxidized Lavery Till is dark brown (10YR 4/3) in contrast to the yellow brown (10YR 4/4) color of the Kent Till. The Lavery Till is leached from 30 to 50 inches. The weathering horizons are shown in Figure 7 as well as in Figure 8, in which sections showing Lavery Till over older material are illustrated. The weathering units observed in the area of thicker Lavery Till by Shepps are shown in his Figure 11 (1955, p. 63, "middle Cary").

These weathering horizons and soil units are similar to those described for the Lavery Till in Stark County, Ohio (White, 1963, p. 135-137). It may be noted that the depth of leaching in the area of thin till in Pennsylvania, south of the Lavery moraine, is generally less than the depth of leaching recorded by Shepps farther north and less than that recorded in Stark County, Ohio. This difference is probably a function of the thickness of the till, rather than of the composition of the till. Low depths of leaching can be recorded in thin till, but higher depths cannot, because leaching has completely penetrated the thin till and thus a true leaching thickness and a true average leaching thickness cannot be secured.

Stratigraphic Position

The Lavery Till is underlain at most places by the Kent Till. At some places the Kent Till is absent and the underlying material is Titusville Till, which exhibits a weathered upper surface below the less weathered and usually calcareous Lavery Till. Where the Kent Till is the underlying material, it may or may not show a weathered upper surface. Figure 8 records columnar sections showing the relation of thin Lavery Till to underlying material, and diagrams of longitudinal sections in Mercer County are illustrated in Figures 40 and 41, and in Erie County in Figures 42 and 43.

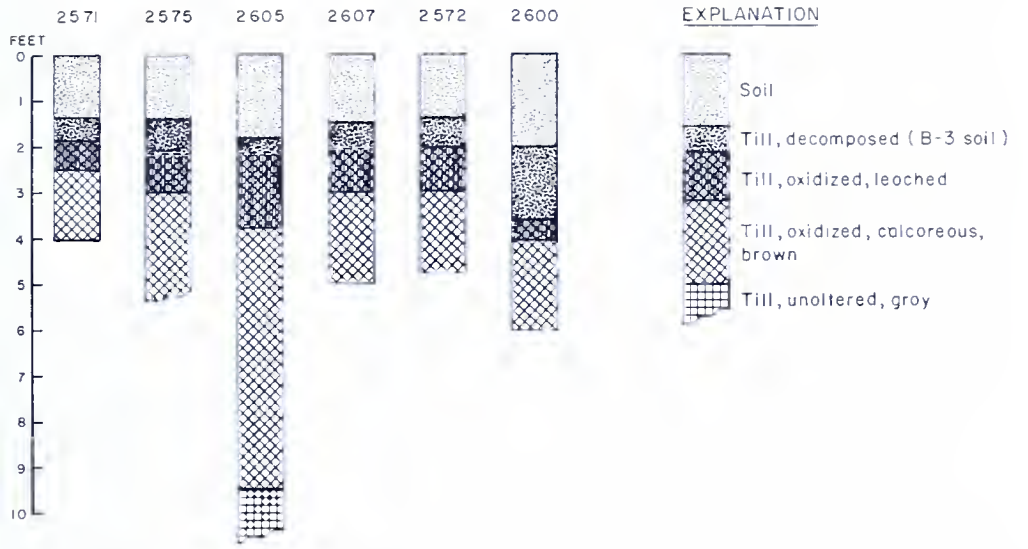

Figure 7. Columnar sections showing weathering horizons of Lavery Till in the "thin-till zone."

2571 Road cut 2½ miles E of Conneautville, Summerhill Twp., Crawford Co.

2575 Bridge excavation for Interstate 79, 1 mile N and ½ mile W of township line, Franklin Twp., Erie Co., 2½ miles W of Edinboro.

2605 Cut bank of Folk Run, ⅛ mile of Mishler Corners, Franklin Twp., Erie Co.

2607 Road cut for Interstate 79 and bridge excavation, ½ mile W of east line, ⅝ mile S of north line, Franklin Twp., Erie Co.

2572 Road cut ½ mile W of Rundell Corners, Spring Twp., Crawford Co.

2600 Road cut and auger boring ¼ mile N of county line, 1 mile E of township line, West Fallowfield Twp., Crawford Co.

The Lavery Till is overlain by Hiram Till north of the area where the Lavery is the surface, but investigation of this relationship was not part of the present study.

Age and Correlation

The age of the Lavery Till is not known precisely, because no organic material for C^{14} dating has so far been discovered in it. However, the lower part of marl preserved below peat in a bog at Corry in extreme eastern Erie County has a minimum age of 14,000 years (Droste, Rubin, and White, 1960) and records the minimum time since the ice retreated from Corry. This bog was formerly thought to be within the area of Kent Till, but it now appears that it probably is at the margin of Lavery Till, and thus the date is a minimum one for the Lavery Till rather than for the Kent Till. The presence of the weathered Kent material at some places below calcareous or less weathered Lavery Till indicates some period of weathering between the deposition of the

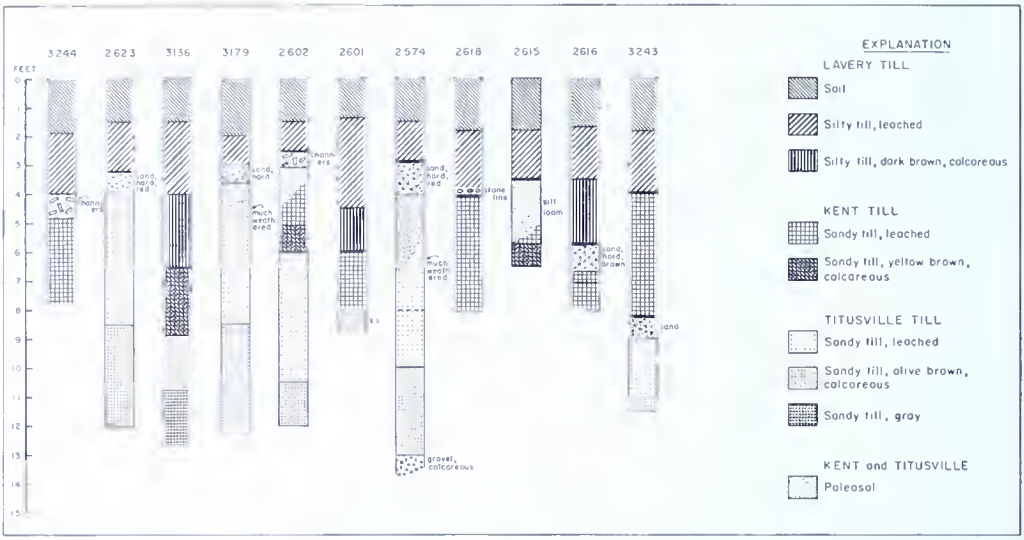

Figure 8. Columnar sections showing thin Lavery Till overlying earlier till.

3244 Road cut on State Line Road, 2½ miles W of Hare Creek, at boundary line Marker 224, Wayne Twp., Erie Co.

2623 Abandoned strip mine ⅜ mile S of north line, 1½ miles W of east line, at N end of Prospect Ridge, South Pymatuning Twp., Mercer Co.

3136 Road cut for Interstate 80, 2 miles E of West Middlesex, Shenango Twp., Mercer Co.

3179 Borrow pit at crossroad, 3 miles SW of Greenville, West Salem Twp., Mercer Co.

2602 Excavation for residence hall at Thiel College, Greenville, Mercer Co.

2601 Above sandstone quarry, Quarry Hill, ⅛ mile W of highway, 2 miles SE of Greenville, Hemphill Twp., Mercer Co.

2574 Gravel pit 1⅛ miles NE of Springboro, Spring Twp., Crawford Co.

2618 Road cut ⅝ mile SE of New Ireland, 2½ miles E of Mill Village, LeBoeuf Twp., Erie Co.

2615 Road cut 1 mile E of Sturgis Corners, ¼ mile S of north line, 1 mile E of west line, Bloomfield Twp., Crawford Co.

2616 Road cut on U. S. Highway 6, ½ mile W of E line, 2 miles N of west line, LeBoeuf Twp., Erie Co.

3243 Road bank ⅝ mile NW of Five Points, 5 miles NW of Corry, Wayne Twp., Erie Co.

two tills. The Lavery Till is now believed to be of late middle Woodfordian age of the Lake Michigan lobe classification of Frye and Willman (1960, p. 2).

The Lavery Till is correlated with the Hayesville Till of the Killbuck lobe (White, 1963, p. 122; 1967, p. 27). It may be correlated with the very latest Catfish Creek drift or possibly with the Port Stanley drift of Ontario described by Dreimanis (1964, Fig. 2).

HIRAM TILL

Examination of the Hiram Till formed only a very incidental part of the present investigation, because this till occupies only a small part of the area and because within that area satisfactory outcrops to show the stratigraphic relationships of underlying tills were not found. However, a summary of this unit is included here for general information.

The Hiram Till is named for a type locality near Hiram, Portage County, Ohio (White, 1960, p. 2). It has been traced from Richland County north of Mansfield in north central Ohio (Totten, 1962, p. 79) through the intervening Ohio counties (Winslow and White, 1966, p. 34) to Pennsylvania (Figs. 1 and 2).

In Pennsylvania it is the surface material of a triangular shaped area in northwestern Crawford County and southwestern Erie County (Shepps and others, 1959, map and Fig. 4). It is overlapped by the Ashtabula Till just south of Erie, but reappears from beneath the Ashtabula Till at the New York state line and continues into New York (Muller, 1963, plate 1).

The Hiram Till is a "bluish gray, sparingly pebbly, calcareous, clay to silty clay till, which oxidizes to a drab brown color" (Shepps and others, 1959, p. 41). The average composition of 30 samples determined by Tharin (1958, p. 28) is 13.7 percent sand, 50.6 percent silt and 35.7 percent clay.

The weathering horizons of the Hiram Till are well shown by Shepps (1955, Fig. 11, "late Cary"). No buried weathering horizons underneath the overlying Ashtabula Till have so far been observed.

The Hiram Till is underlain by the Lavery Till and overlain by the Ashtabula Till. No outcrops to show these relationships were noted in this field study, but from previous work it is known that in the region of the Ashtabula morainic system these three tills are present. At places, sand and gravel separate the tills and the stratigraphic arrangement is similar to that in Lake County, Ohio (White, 1962, p. C97).

ASHTABULA TILL

The Ashtabula Till is named from the city of Ashtabula, Ashtabula County, Ohio, near which the unit is well exposed. The type section is

3 miles east of the city of Ashtabula (White, 1960, p. A10). It has been traced from a point just east of Cleveland, Ohio, northeastward in a belt 2 to 8 miles wide parallel to Lake Erie, across Pennsylvania into New York. The till occurs in a series of prominent end moraines known as the "Ashtabula morainic system" (Shepps, 1955, p. 76; Shepps and others, 1959, p. 45).

The Ashtabula Till is gray to bluish silt till having an average composition of 31.3 percent sand, 45.4 percent silt, and 23.3 percent clay (Tharin, 1958, p. 31). Ashtabula Till is more sandy than the Hiram Till and is very similar to the Lavery Till in composition. The oxidized Ashtabula Till is brown in color, resembling the Lavery Till in appearance. The weathering horizons of the Ashtabula Till are shown by Shepps (1955, Fig. 11, "latest Cary").

The Ashtabula Till is underlain by the Hiram Till, but the stratigraphic relations were not part of this investigation. It is known, however, that not all of the till of the Ashtabula morainic system is Ashtabula Till (White, 1962, p. C97, Fig. 95.3). In a belt from 2 to 4 miles wide between Lake Erie and the Ashtabula moraines, the Ashtabula Till has been in part removed by erosion of the higher late glacial levels of Lake Erie and in part the till is overlain by sand and gravel deposited in the higher levels of the lake.

PETROGRAPHY AND AREAL VARIATION OF THE TILLS

INTRODUCTION

A part of this investigation was concerned with the petrography of the tills — their texture, mineral composition, and areal variation. The Titusville Till was investigated in the greatest detail because it composes the bulk of drift of northwestern Pennsylvania, and 155 samples were analyzed for texture and 100 for feldspar content. Only 24 samples of Mapledale Till and 43 samples of Kent Till were available. Fifteen samples of Lavery Till were analyzed.

Samples of calcareous till were collected from the different units at the outcrops studied. The texture was determined as percentage of the coarse fraction (10.0 to .062 mm), hereafter called "sand"; silt (.062 to .004 mm); and clay (less than .004 mm).

Heavy minerals in the .125-.177 mm size fraction were separated by standard methods and are now the subject of study and are reported here only very briefly.

The light minerals, quartz and feldspar, of the .125-.177 mm size fraction were separated by standard staining methods and the percentage of each determined. The percent potash and plagioclase feldspar were determined.

The carbonate content was determined for sufficient samples to provide mean figures for Kent, Titusville, and Mapledale Tills.

The data for all the samples analyzed are recorded in tables elsewhere (Gross, 1967, p. 13-32), and only the means are shown in Table 2. Note, however, that these means are for samples scattered over a wide area and that there is a real variation of the values which will be discussed in some detail. The significant differences among these means at the 95 percent confidence level determined by a "two-tailed *t* test" is discussed by Gross (1967, p. 11).

Now that computers are available for statistical analysis of geologic data, the complexities of a contour map of values can be resolved by calculation of least squares fit trend surfaces. Calculations using the present data were done on the University of Illinois IBM 7094 computer and the computed printouts for these studies are given in the detailed studies by Gross (1967). A first order trend surface, calculated by a digital computer, indicates the amount (value per mile) and direction of any gradations present. These gradations will be discussed for each till and the direction and amount are shown by vectors on Figure 9.

Second order trend surfaces show variations in direction of isopleths, an example of which will be illustrated. The use of trend surfaces for geological studies is discussed by Dillon (1967) where references to statistical works are given. Dillon's Figure 10 and accompanying equations are especially pertinent.

TEXTURE

Introduction

The texture — sand, silt, and clay content — differs among the tills and varies laterally within individual till units. Sitler (1957, Figs. 7-10) showed the variation of the "Wisconsin" Till of Lawrence and southern Mercer Counties by contour maps, and Tharin (1958, Fig. 8) showed the variation along the state line by a graph showing horizontal and vertical values. Variations were shown in a series of diagrams by Shepps and others (1959, Fig. 7-10). Thin section studies by Sitler and Chapman (1955) and by Sitler (1963) include photomicrographs of Hiram, Kent, and Mogadore (correlative with Titusville) Tills from Ohio showing textures of these tills and the differences between them. The results of the present studies will be discussed for each till.

Mapledale Till

The Mapledale Till is a somewhat sandy till, as shown by the mean values recorded in Table 2. The Mapledale Till has a slightly higher clay content than the Titusville Till or the Kent Till, but the data are insufficient for meaningful statistical analyses of direction and amount of variation.

Table 2. *Mean texture and composition of tills*
(Number of samples used to determine mean shown in parentheses)

UNIT	*% Sand*	*% Silt*	*% Clay*	*% Quartz*	*% Feldspar*	*% K Feldspar*	*% Heavy Minerals*	*% Calcite*	*% Dolomite*	*% Total Carbonate*
Lavery Till	32.7 (15)	47.0 (15)	20.3 (15)	68.9 (11)	31.1 (11)	31.9 (11)	3.7 (11)			
Kent Till	43.0 (43)	38.5 (43)	18.5 (43)	86.9 (22)	13.1 (22)	44.7 (22)	2.2 (18)	1.4 (3)	1.8 (3)	3.2 (3)
Titusville Till	45.4 (155)	36.9 (155)	17.7 (155)	87.9 (100)	12.1 (100)	52.9 (100)	2.9 (96)	1.1 (9)	1.3 (9)	2.4 (9)
Mapledale Till	44.0 (24)	36.0 (24)	20.0 (24)	94.6 (24)	5.4 (24)	53.1 (24)	2.1 (21)	0.7 (9)	0.6 (9)	1.3 (9)

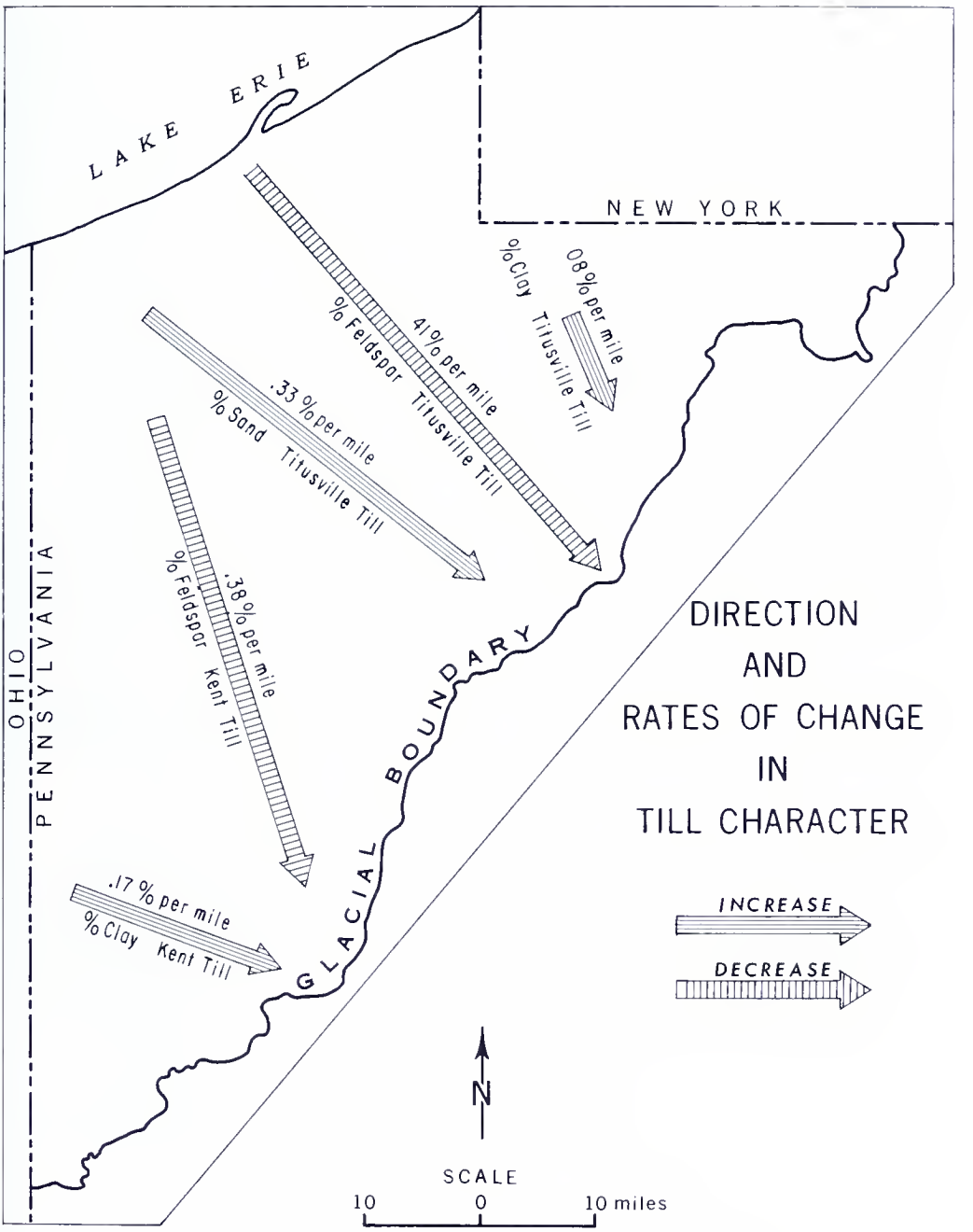

Figure 9. Direction and rates of change in till character.

Titusville Till

The Titusville Till is a sandy till (Table 2); the sand content increasing toward the margin. The first order trend surface for the sand content of the Titusville Till indicates an increase of 0.33 percent sand per mile in a direction S. 52° E. essentially normal to the till boundary (Fig. 9).

The second order trend surface computed for the Titusville sand content shows an interesting pattern of directional change. The isopleths drawn from the computer printout of the second order surface are illustrated in Figure 10. (Isopleths on a first order surface are necessarily straight, but those on a second order surface may have one inflection of curvature.) In the southern and western part of the area the direction of increase in sand is to the southeast whereas in the northern and northeastern part of the area the direction of increase is to the south and even to the southwest. Whereas in the first order surface the isopleths are parallel to the till margin, in the second order trend surface map the isopleths turn to a direction in which they are almost perpendicular to the till margin in the few miles adjacent to this margin, especially in the northeastern part of the area. Isopleths normal to the direction of ice flow indicate that the till texture was changing in the direction of ice flow. Isopleths parallel to the direction of ice flow indicate that the till texture remained constant as the ice continued to advance. These studies therefore show that the texture of the till changed in the southeasterly direction of ice flow, until the ice approached its margin, after which the texture remained constant.

The first order trend surface map of the clay values of Titusville Till shows a very minor trend of 0.08 percent per mile, in a direction S. 25° E. (Fig. 9).

Kent Till

Trend surface analysis of sand in the Kent Till does not show any significant trends. Note, however, that this analysis is based on 43 samples at 33 locations as compared to 155 analyses at 74 locations for the Titusville Till, for which more definite directional trends are evident. More detailed sampling of the Kent Till might give some indication of directions of variation.

Trend surface analysis of the clay values shows an increase of 0.17 percent per mile to the southeast with the trend oriented S. 65° E. (Fig. 9).

Lavery Till

The Lavery Till is a silty till as shown by the mean values recorded in Table 2. Statistical analyses of direction and amount of variation cannot be calculated from the few data available. However, our impression from field observation is that the texture becomes coarser toward the margin of the Lavery Till area, especially in the northeastern part of the area, where the soil types appear to be somewhat more coarse textured than those farther north and west.

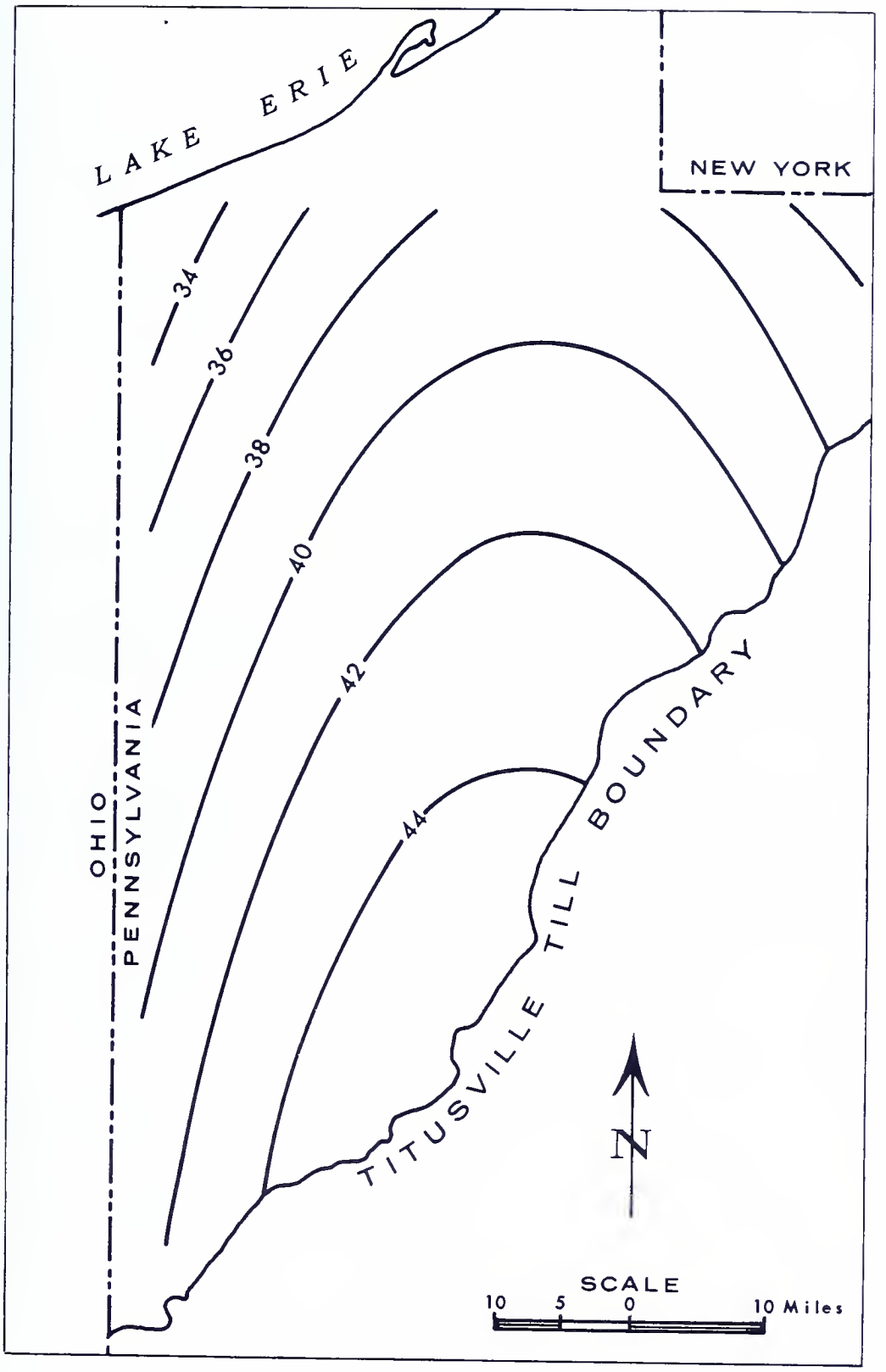

Figure 10. Second order trend surface of percent sand in Titusville Till.

FELDSPAR CONTENT

Introduction

The light minerals were studied in the 0.125-0.177 mm (fine sand) fraction and complete tables to show quartz and feldspar percentages for each sample are given in a report by Gross (1967). The mean values for each till are shown in Table 2. Totten (1960) and Heath (1963) have reported on the feldspar content of tills and their variation in Ohio. The kinds of quartz were not obvious in the studies made.

The feldspar was chosen for detailed study because of the ease of identification and separation from the quartz by hydrofluoric acid treatment and staining agents. The potash feldspars are also clearly separated from the plagioclase feldspars by this method.

Mapledale Till

Mapledale Till contains 5.4 percent feldspar in comparison to 12.1 percent in the overlying Titusville Till. This difference is significant at the 95 percent level of confidence. Of the 5.4 percent feldspar in the Mapledale Till, 53.1 percent is potassium feldspar, which is very close to the value of 52.9 percent potassium feldspar in Titusville Till. The percent of feldspar of Mapledale Till is plotted on the sample locations in Figure 11. The higher feldspar percentages to the northwest indicate a decrease in feldspar in a southeastern direction, but samples are too few for statistical analysis.

Titusville Till

One hundred samples of Titusville Till contained a mean of 12.1 percent feldspar, of which 52.9 percent was potassium feldspar. The percent of feldspar is plotted on the map of sample locations in Figure 12, on which 10 and 20 percent isopleths are drawn. A decrease in percent of feldspar to the southeast is very apparent.

A first order least squares fit trend surface shows a decrease in percent feldspar within Titusville Till of .41 percent per mile to the southeast (Fig. 9). This direction of trend, S. 41° E., is almost normal to the till boundary. The second order trend surface, Figure 13, shows the isopleths bending to the southeast near the till boundary. The same tendency is shown in the isopleths drawn manually on Figure 12. The change in direction of decrease of feldspar content is somewhat similar to the change in direction of isopleths showing increasing sand content toward the margin of the till (Fig. 10) and the same cause may account for both patterns. These trend surfaces indicate that the composition of the till changed in the direction of ice flow, until the ice approached its border, after which the composition of the till remained constant. The isopleth lines parallel to the direction of ice flow mean that the till composition remained unchanged in its last few miles of flow.

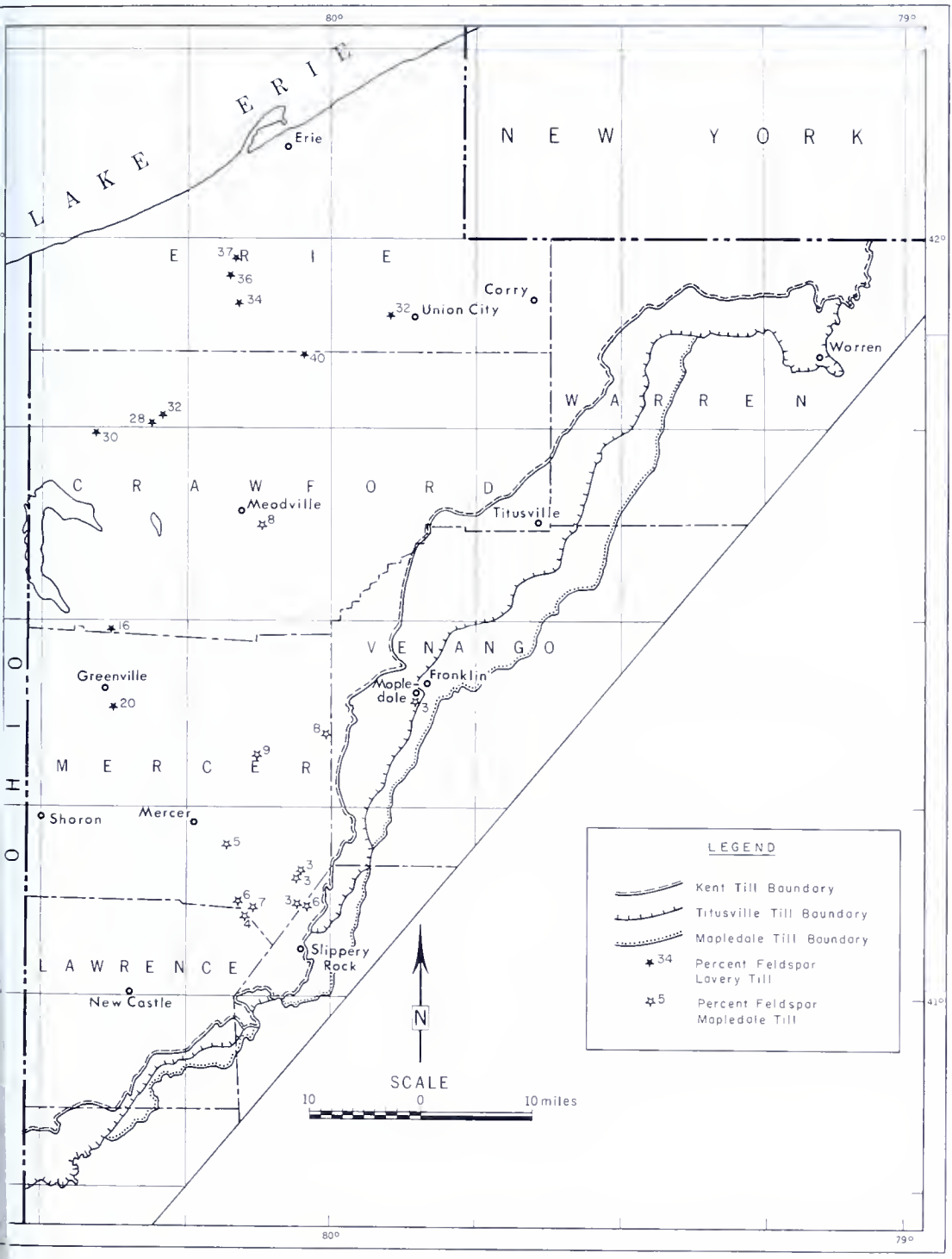

Figure 11. Percent feldspar of the the .125-.177 mm size fraction, Lavery Till and Mapledale Till.

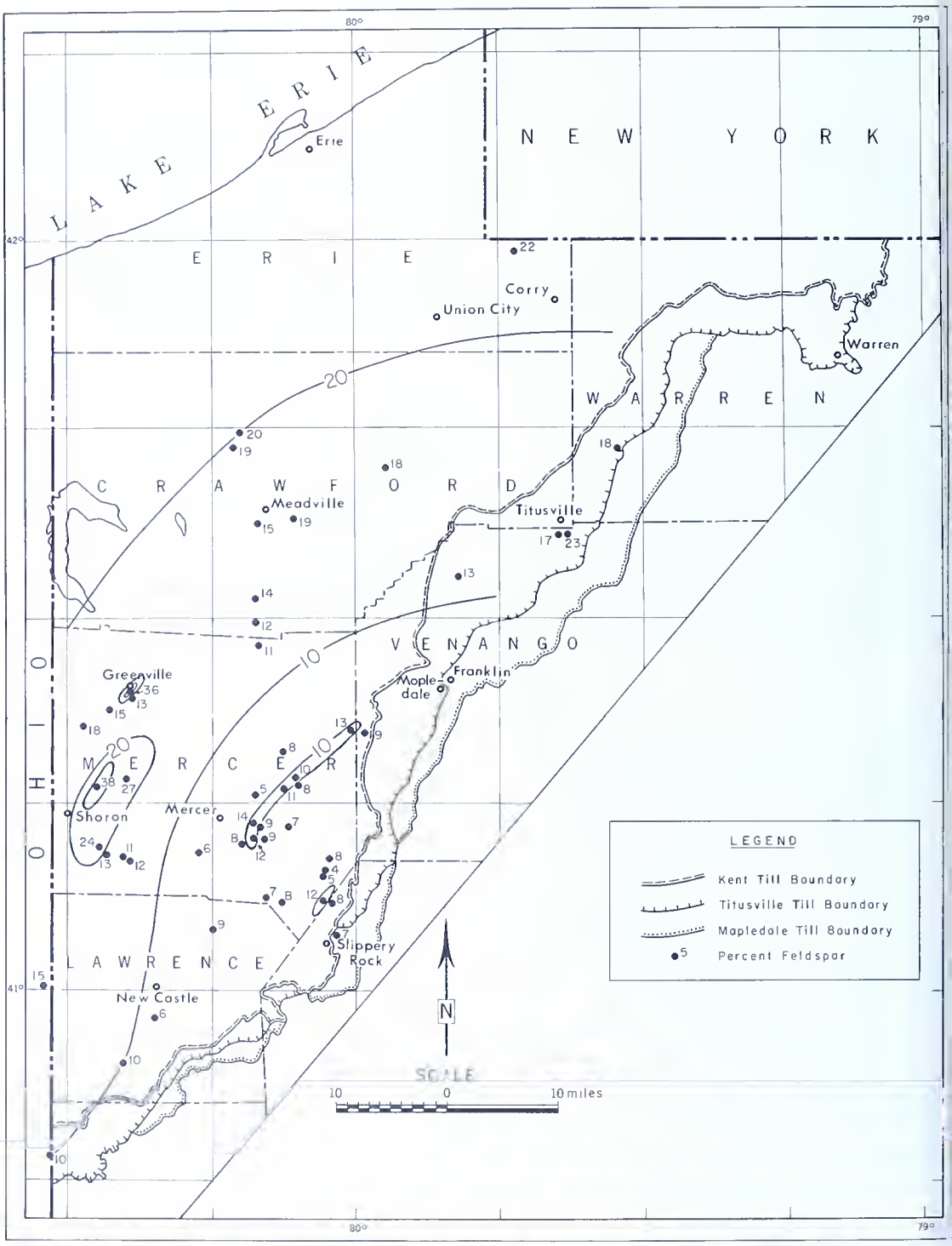

Figure 12. Percent feldspar of the .125-.177 mm size fraction, Titusville Till.

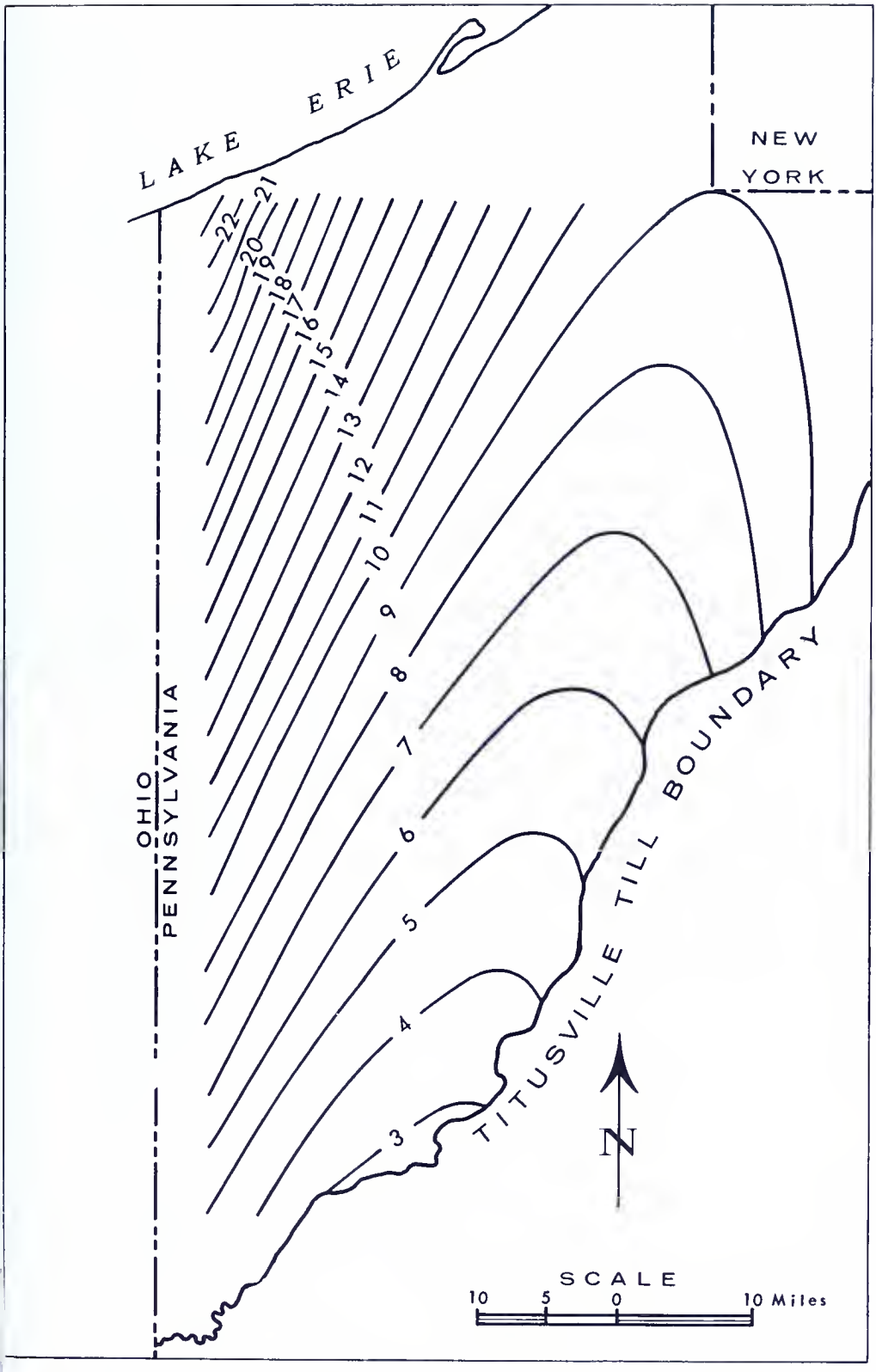

Figure 13. Second order trend surface of percent feldspar in Titusville Till. Data are from Figure 12.

Kent Till

Kent Till contains slightly more feldspar, 13.1 percent, than Titusville Till, which contains 12.1 percent. Kent Till contains less potassium feldspar, 44.7 percent as opposed to 52.9 for Titusville Till. This difference in potassium feldspar content is significant at the 95 percent confidence level. The percent feldspar of Kent Till is plotted on the sample locations in Figure 14. The 10, 20, and 30 percent isopleths clearly show an increase in percent feldspar to the northwest. The first order trend surface shows a gradient decrease to the south-southeast of .38 percent per mile. Again, the change is approximately normal to the till boundary.

Lavery Till

As was the case for the textural data, a meaningful trend surface cannot be calculated for either Lavery Till or Mapledale Till because of the lack of data points. Lavery Till contains 31.1 percent feldspar as compared to only 13.1 percent in the underlying Kent Till. Similarly, Lavery Till contains less potassium feldspar than Kent Till, 31.9 percent as compared to 44.7 percent. These differences are both significant at the 95 percent level of confidence. The percent feldspar of Lavery Till is plotted on the sample locations on Figure 11. There is some indication of a compositional gradation within the unit, a gradation which is in the same direction as was found for Titusville and Kent Tills.

POTASSIUM FELDSPAR

The potassium feldspar percentage of the total feldspar content was determined and the means for each stratigraphic unit are presented in Table 2. Sample value maps were plotted and trend surfaces were calculated for the percentage of potassium feldspar, but significant gradation was found in only one of the tills. The first order trend surface for the percent potassium feldspar of Titusville Till shows an increase of .5 percent per mile to the southeast (S. 52° E.). The most significant aspect of the gradation is its orientation normal to the till margin, the same orientation as is seen in both the textural analyses and the percent feldspar plots.

HEAVY MINERALS

The percent of heavy minerals in the .125-.177 mm size fraction was calculated and the mean values for each stratigraphic unit are presented in Table 2. Lavery Till contains the greatest percentage of heavy minerals, with Mapledale Till containing the least percentage. The decrease in percentage from younger to older is interrupted by the anomalously low value for Kent Till. No gradations in percent within individual till

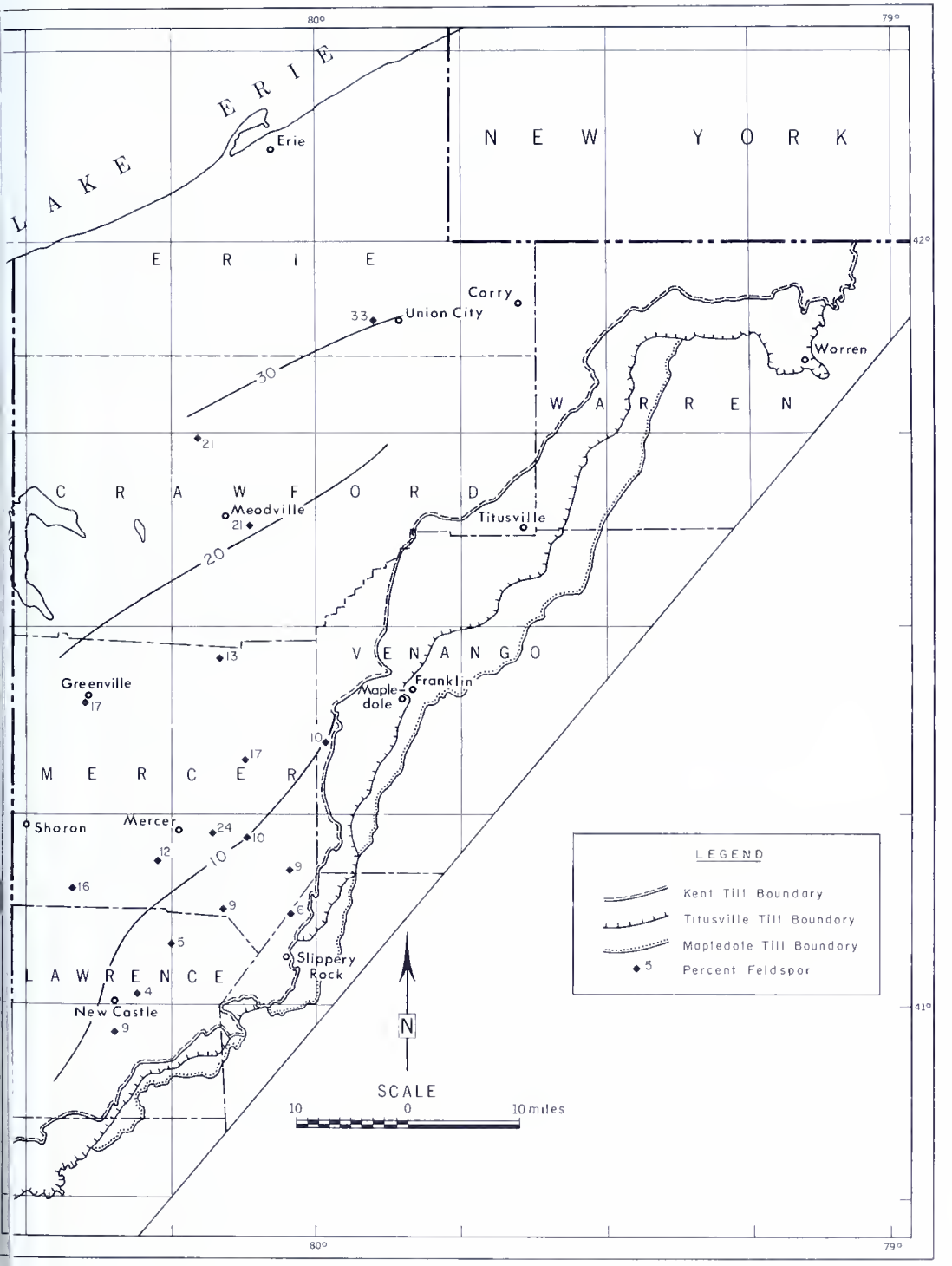

Figure 14. Percent feldspar of the .125-.177 mm size fraction, Kent Till.

units, either vertically or areally, were found. It is concluded that the percent heavy minerals in this size fraction does not aid in till identification. Sitler (1957, p. 55; 1963) has studied the heavy minerals of Ohio and part of Pennsylvania and his reports contain excellent descriptions of the various kinds of heavy minerals and their distribution.

CARBONATE

The carbonate content, both calcite and dolomite, of some of the samples was determined and the mean values for Kent, Titusville, and Mapledale Tills are presented in Table 2. It had been observed in the field that unweathered Mapledale Till did not react visibly with dilute hydrochloric acid. Samples of this till were found to contain only 1.3 percent carbonate, which explains its slow reaction with hydrochloric acid. There is a significant increase in carbonate percentage in the younger tills.

Carbonate content of 122 samples of Titusville Till (and a few of Kent Till) near the Ohio-Pennsylvania line was determined by Moran (1967, p. 26-27, pl. 4). He found that: "Carbonate content increases rapidly to 65 inches below the depth of leaching and then more slowly to 118 inches. Below 118 inches the carbonate content decreases slightly or remains constant with depth to approximately 320 inches, where the rate of decrease became more rapid".

PLEISTOCENE HISTORY

INTRODUCTION

The Paleozoic sedimentary rocks of northwestern Pennsylvania were uplifted at the end of that era and erosion took place for about 200 million years during the whole of Mesozoic and Tertiary time. At the end of the Tertiary Period a time of lowered temperature and persistence of snow ushered in the Pleistocene or "Glacial" Epoch, somewhat more than one million years ago. Four times during the Pleistocene, ice sheets formed over Labrador and spread out from this center. Ice flowed southwest into the basin of the Great Lakes and spread south and southeast into northwestern Pennsylvania from the Erie basin.

Between each of the glacial stages the ice completely disappeared in times of warmer climate, similar to that of today, and weathering and erosion of the glacial deposits took place. During the last glacial stage, the Wisconsinan, the ice front fluctuated, advancing and retreating for distances of a few miles to several hundred miles. Similar advances and retreats in the three earlier glacial stages, the Nebraskan, Kansan, and Illinoian, also took place in the Mississippi Valley, but the evidence for such fluctuations in Pennsylvania is not as clear.

The history of the advances and retreats in northwestern Pennsylvania is determined from the deposits of the successive ice sheets and from the weathered zones upon the deposits as described in this report. A time-space diagram, Figure 15, has been constructed to present a summary of the history.

VERY EARLY PLEISTOCENE

The earliest advances of ice into the Allegheny Plateau blocked the northward flowing streams (Leverett, 1902). Till of this earliest advance has not been identified and the earliest ice may not have reached very far into the Allegheny Plateau. Lakes, probably shallow on the uplands, existed at this time as recorded by silt in a depression at Parker, which is beyond the limit of known drift, and beneath Slippery Rock Till at Valcourt.

"PRE-ILLINOIAN" STAGE

The earliest ice sheet advance into northwestern Pennsylvania that left a record in the form of a till deposit was that which laid down the Slippery Rock Till. This ice sheet advanced almost to the position reached by the later ice that deposited the Mapledale Till. It is not possible to determine whether this earliest advance was in Nebraskan or Kansan time.

The deposition of the Slippery Rock Till was followed by a long period of weathering, which may represent either the Aftonian or Yarmouthian interglacial stage in the Mississippi Valley.

ILLINOIAN (?) STAGE

After a long interglacial period of weathering following the deposition of the Slippery Rock Till, Illinoian (?) ice invaded northwestern Pennsylvania and extended farther than any later ice sheet. The Mapledale Till was deposited and extensive gravel deposits were laid down in the vicinity of Franklin. It is probable that some, or even much, of the gravel recorded in deep valleys is of this age.

There were at least two advances of ice in Illinoian (?) time, as shown by the fact that Mapledale Till at some places is composed of two sheets of different lithology and mineralogy.

SANGAMONIAN (?) INTERGLACIAL STAGE

An interglacial period of warmer climate, in which the ice disappeared, followed the deposition of the Mapledale Till. During this time long continued weathering produced deep oxidation, deep leaching, and a thick soil. This long period of weathering is pre-Titusville and pre-

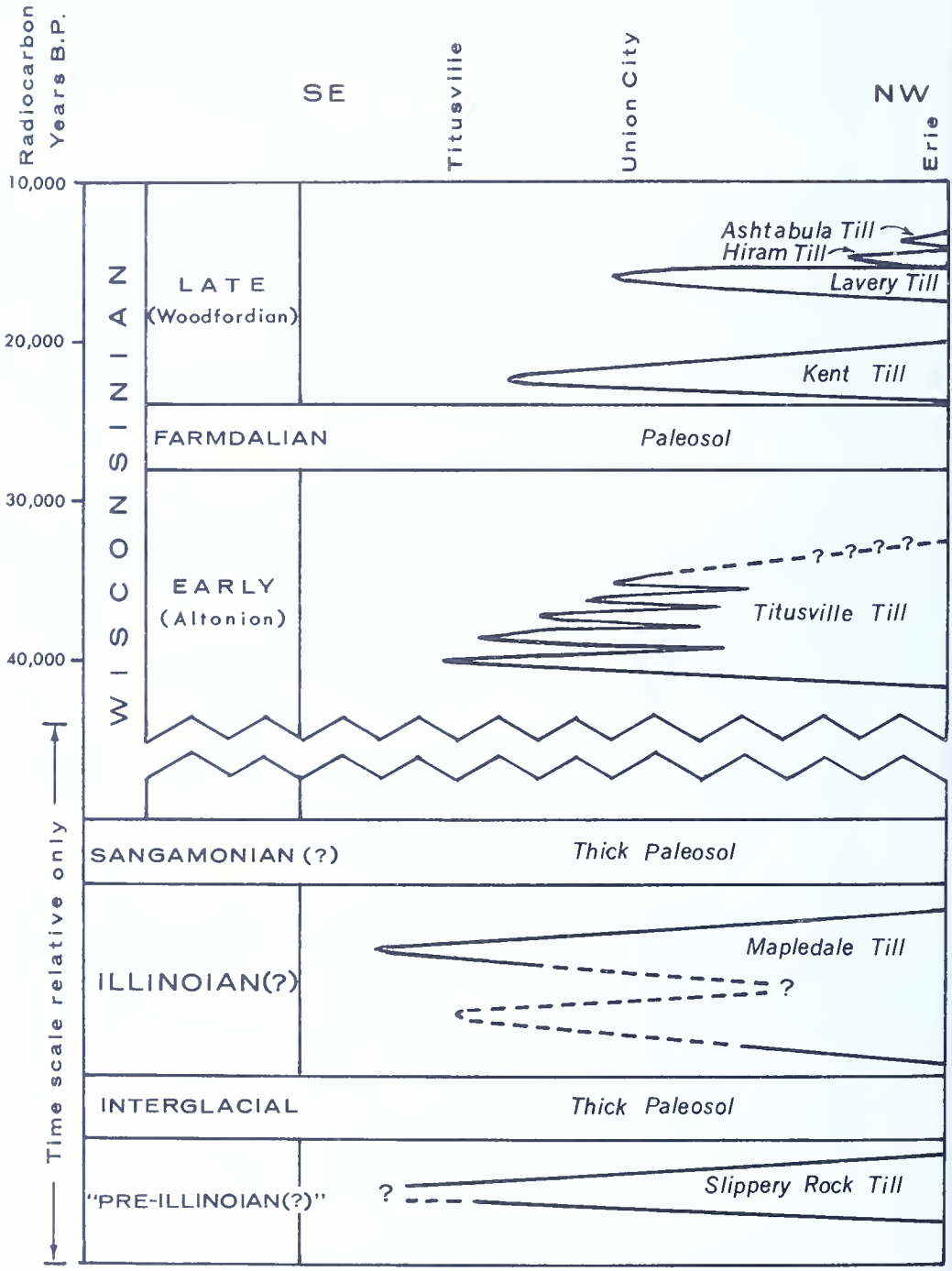

Figure 15. Time-space diagram of glacial deposits in northwestern Pennsylvania. The diagram is arranged from Lake Erie southeast through Union City and Titusville.

sumably is that time between the Wisconsinan and Illinoian glacial stages known as Sangamonian. However, as this paleosol on the Mapledale Till of northwestern Pennsylvania cannot be traced to the Sangamon paleosol of the type locality in Illinois, it is preferable to refer to this time of interglacial climate in Pennsylvania as "Sangamonian (?)."

WISCONSINAN STAGE — EARLY (ALTONIAN) SUBSTAGE

After the deposition and long weathering of the Mapledale Till, the climate again became more rigorous and ice again invaded northwestern Pennsylvania to usher in the latest glacial stage, the Wisconsinan. During the Wisconsinan stage an interstadial time of several thousand years of warmer climate (the Farmdalian interval) brought about melting of the ice and Pennsylvania and all of the Great Lakes basins were deglaciated. In the area of the Lake Michigan lobe the early Wisconsinan substage has been named Altonian and the late substage Woodfordian by Frye and Willman (1960) and it is convenient to use these names for substages of the same time in the Grand River lobe in Pennsylvania and Ohio.

Titusville

In early Wisconsinan (Altonian) time ice again advanced into northwestern Pennsylvania and deposited the Titusville Till. Although the Titusville ice did not advance at most places quite as far as the earlier Mapledale ice, it deposited the greatest thickness of till in northwestern Pennsylvania and thicknesses greater than 75 feet are known. The ice picked up more and more local material as it advanced, producing a progressive decrease in minerals, such as feldspar, that it had brought to the margin of the plateau.

The Titusville ice advanced and retreated for unknown distances (perhaps a few tens of miles) at least three, and possibly five times, as is recorded by separate sheets within the Titusville Till deposit. The time between each of the advances is not known, but is believed not to be very long, as only slight indications of weathering have been discovered at the surface of any of the sheets below the uppermost one.

The later advances reached about the same limit along a zone from 10 to 15 miles within the outer limit of the earliest advance and "stacked up" drift several tens of feet in thickness to form an end moraine 3 to 15 miles wide. This moraine was later covered by Kent Till and is known as the Kent moraine.

The onset of the Titusville ice advance was about 40,000 years ago and the ice may have persisted in northwestern Pennsylvania for several thousand years.

FARMDALIAN INTERVAL

After the retreat of the ice sheet that deposited the uppermost Titusville Till, a period of weathering and erosion followed. It was at least several thousand years in length — time enough for the formation of a weathered zone which is preserved on the Titusville Till at places beneath overlying Kent Till. It was also long enough to provide a much deeper weathering on the Titusville Till beyond the Kent boundary than that on the Kent Till of the next ice advance.

WISCONSINAN STAGE — LATE (WOODFORDIAN) SUBSTAGE

After the Farmdalian interval of weathering, ice again advanced over northwestern Pennsylvania and in this late Wisconsinan (Woodfordian) substage several advances and retreats took place. The first ice advance in this substage began about 24,000 years ago and it may have reached northwestern Pennsylvania about 23,000 years ago.

Kent

The Kent ice advanced into northwestern Pennsylvania about 23,000 years ago and deposited in most places a very thin layer of till. The Kent ice retreated into the Lake Erie basin and some weathering took place on the surface of the Kent Till.

Lavery

After the retreat of the Kent ice into the Erie basin, the ice sheet readvanced to deposit the Lavery Till. The maximum extent of this ice, which was from 10 to 20 miles less than that of the Kent ice, reached its farthest limit more than 14,000 years ago; perhaps 16,000 years is a reasonable conjecture. The Lavery ice sheet deposited a very thin layer of till, especially in its outer 10 to 15 miles of advance. Ten or fifteen miles back of the margin, thicker till was deposited at the location of the Lavery moraine, which however, is made up, at least in part, of earlier till. The Lavery ice retreated into the Erie basin.

Hiram

The Hiram ice advanced from the Erie basin to a position generally along the escarpment marking the northwest margin of the Allegheny Plateau. In a part of northwestern Pennsylvania its margin was controlled by the higher land of the Lavery moraine which it could not surmount. The Hiram ice retreated to an unknown distance, but almost certainly into the Lake Erie basin.

Ashtabula

The Ashtabula ice advanced out of the Erie basin to a line along the base of the escarpment marking the northwest margin of the plateau. This ice deposited somewhat coarser material than was carried by the Hiram ice.

POST-WISCONSINAN

After the retreat of the ice that deposited the Ashtabula Till, no later ice advances entered Pennsylvania, but they did approach sufficiently close to back up waters in the Erie basin to form successive high level lakes. "The higher waters reworked the previously laid till deposits and deposited sand and gravelly sand as blanket deposits and beach ridges along a wide plain south of the present shore of Lake Erie. During all of the time that northwestern Pennsylvania was free of ice the previously deposited materials were subjected to subaerial erosion and weathering, and were locally worked and redeposited as stream alluvium or as lake and swamp deposits" (Shepps and others, 1959, p. 48-49).

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APPENDIX I

MEASURED SECTIONS

Blum Road Strip Mine Section

Section measured in strip mine 3½ miles north-northwest of Grove City, 200 yards west of Blum Road, Wolf Creek Township, Mercer County (Sample numbers shown in parentheses).

	Unit Thickness	*Aggregate Thickness*
Late Wisconsinan:	*Ft. In.*	*Ft. In.*
Kent Till:		
Silt loam, brownish gray	0 8	0 8
Silt loam, yellow	0 8	1 4
Silt loam, mottled, yellow and brown, colluvium-like	0 8	2 0
Weathered till, yellow and brown	2 0	4 0
Till, as below but noncalcareous, dark yellow-brown, 10YR 4/4	2 8	6 8
Till, sandy, yellow-brown, blocky, calcareous, lower 1 foot with sand streaks, (2379)	4 0	10 8
Early Wisconsinan:		
Titusville Till:		
Till, hard, olive-brown, 2.5Y 4/4, calcareous, (2378)	4 0	14 8
Till, hard, dark gray-brown, 2.5Y 4/2 (to 3/2), stony at base, (2377); Titusville I	8 4	23 0
Sand and gravel	0 6	23 6
Till, very dark gray-brown, 2.5Y 3/2, calcareous, stony at base, (2376); Titusville II	8 0	31 6

	Unit Thickness Ft. In.	Aggregate Thickness Ft. In.
Till, compact, hard, stony, very dark gray-brown, 2.5Y 3/2 (appears more dark than above), (2375); Titusville II	7 0	38 6
Sand, gray, ranges from 1 to 3 feet	3 0	41 6
Till, sandy, not as compact as overlying till, "bright" appearance, very dark gray, 10YR 3/1, (2374); Titusville III	5 0	46 6
Till, as above, but very dark gray-brown, 2.5Y 3/2, ("drab"), (2373); Titusville IV (?)	3 0	49 6
Sand, ranges to 3 feet	0 1	49 7
Till, "very calcareous," dark gray, 5YR 4/1, ("lilac gray"), (2372); Titusville V (?)	3 5	53 0
Illinoian (?):		
Mapledale Till (?):		
Till, weakly calcareous, dark gray-brown, 2.5Y 4/2 to brown, 10YR, (2371)	15 0	68 0
Shale	1 0	
Water level		

Ambrosia Strip Mine Section

Section of glacial deposits measured in strip mine of G. M. Ambrosia Co., ⅜ mile south of Voster Road, 3 miles south of Volant, Washington Township, Lawrence County (Sample numbers shown in parentheses).

	Unit Thickness Ft. In.	Aggregate Thickness Ft. In.
Late Wisconsinan:		
Kent Till:		
Silt loam, dark gray-brown	0 10	0 10
Silt loam, somewhat clayey, yellow to tan	0 10	1 8
Silt loam, clayey, mottled yellow, orange and brown	0 10	2 6
Till, very much weathered, dark brown and gray	1 10	4 4

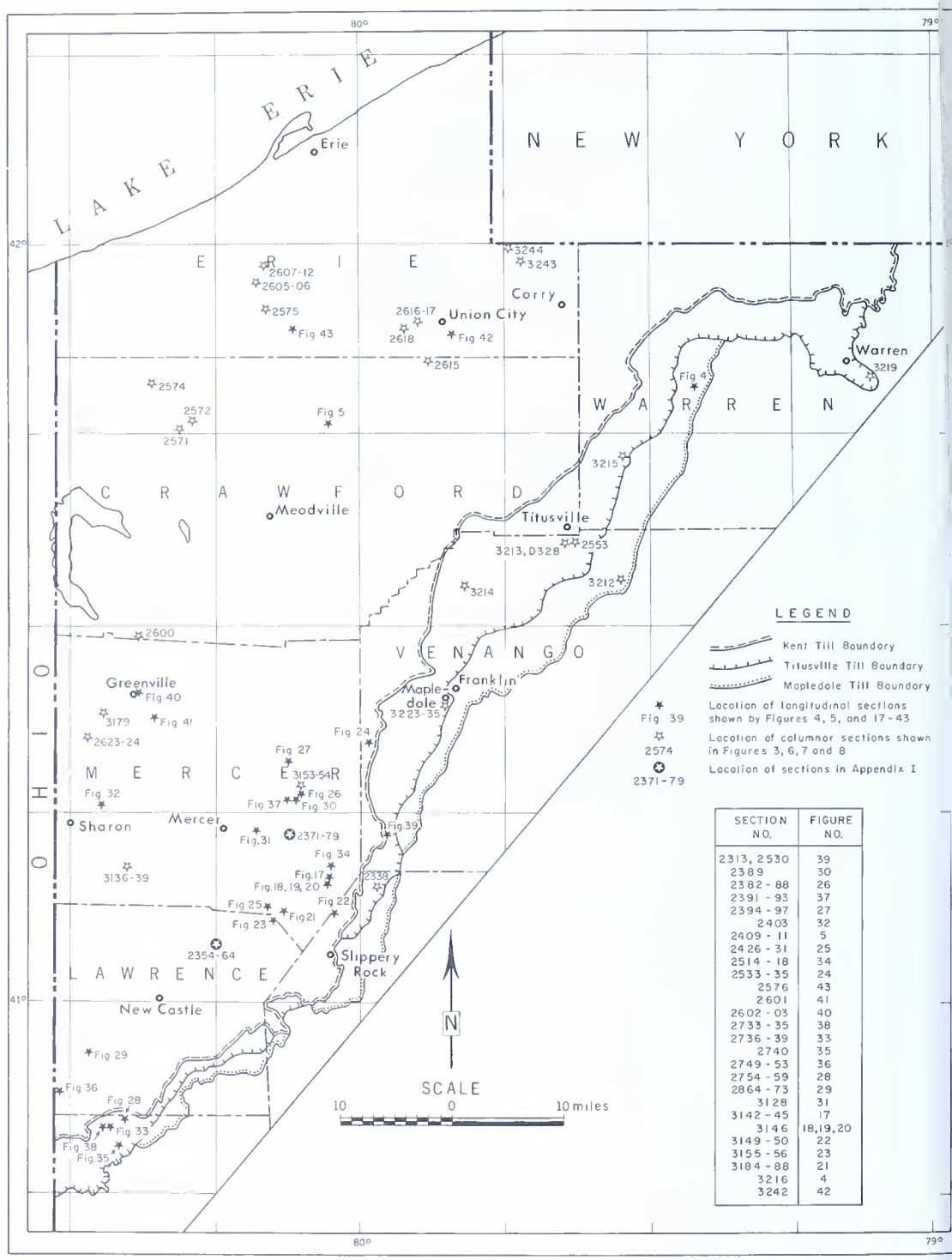
	Unit Thickness Ft.	In.	*Aggregate Thickness* Ft.	In.
Till, yellow-brown, fresh, but noncalcareous	1	6	5	10
Till, dark yellow-brown 10YR 4/4, sandy, pebbly, calcareous, (2364)	3	0	8	10
Till, very dark-gray 5Y 3/0, mixed with brown, calcareous, (2363)	3	0	11	10
Early Wisconsinan:				
Titusville Till:				
Till, weathered, heavily stained along joints, with gray clay seams, noncalcareous, olive 5Y 4/3	1	8	13	6
Till, sandy, pebbly, olive 5Y 4/3, irregular horizontal partings, calcareous, (2362); Titusville I	2	0	15	6
Till, a very dark gray 5Y 3/0, ("bright" gray), calcareous, sharp color difference with till below, texture as above, sand streak near top, (2361); Titusville I	6	6	22	0
Sand, gray, very calcareous, bedding conspicuous, nearby thickness increases to 4 feet for 100 yards of highwall face, 2 feet ± unconformity at top, water-bearing, causing extensive slumping along highwall	0	4	22	4
Till, olive-gray 5Y 4/2 ("drab"), strong contrast to "bright" gray till above, less calcareous than till below. Throughout the pit this unit is distinctive along the highwall, (2360), transitional to unit below; Titusville II	14	10	37	2
Till, dark-gray 5Y 4/0 ("bright"), transitional to unit above, more calcareous than above, (2359); Titusville II	3	0	40	2
Sand and gravel	0	10	41	0

	Unit Thickness Ft.	In.	*Aggregate Thickness* Ft.	In.
Till, sandy, pebbly, very dark gray-brown 2.5Y 3/2 ("drab gray"), calcareous, but "slow to start," (2358); Titusville III	7	6	48	6
Sand, coarse, purple, garnetiferous, ranges from ¼ to 1 inch, (2357)	0	½	48	6
Till, very dark gray-brown 2.5Y 3/2, similar to till above the sand, (2356); Titusville IV (?)	1	4	49	10
Till, as below, yellow-brown, weakly to noncalcareous, thickness ranges from 0 to 2 feet	0	6	50	4
Till, dark olive-gray 5Y 3/2, moderately calcareous, sandy, pebbly, (2355); Titusville V (?)	2	4	52	8
Silt and sand, with a few pebbles (thickness varies), noncalcareous, dark gray, with brown layers	1	2	53	10
Illinoian (?):				
Mapledale Till:				
Plastic clay and clay loam, light yellow-brown, with some pebbles and erratics, much weathered and noncalcareous, ranges from 6 inches to 3 feet, (2354)	1	7	55	5
Clay, light gray, some shale pebbles, one or two rounded sandstone pebbles	0	4	55	9
Brown clay	0	1	55	10
Coal, Lower Kittanning, irregular, unconformity at top, coal completely cut out to west				

APPENDIX II

SKETCHES OF LONGITUDINAL SECTIONS OF PLEISTOCENE UNITS EXPOSED IN STRIP MINES, QUARRIES, AND ROAD CUTS

(Figures 16-43)
Locations of sections are shown in Figure 16



SECTION NO.	FIGURE NO.
2313, 2530	39
2389	30
2382-88	26
2391-93	37
2394-97	27
2403	32
2409-11	5
2426-31	25
2514-18	34
2533-35	24
2576	43
2601	41
2602-03	40
2733-35	38
2736-39	33
2740	35
2749-53	36
2754-59	28
2864-73	29
3128	31
3142-45	17
3146	18, 19, 20
3149-50	22
3155-56	23
3184-88	21
3216	4
3242	42

Figure 16. Location of sections illustrated in Figures 17 to 43.

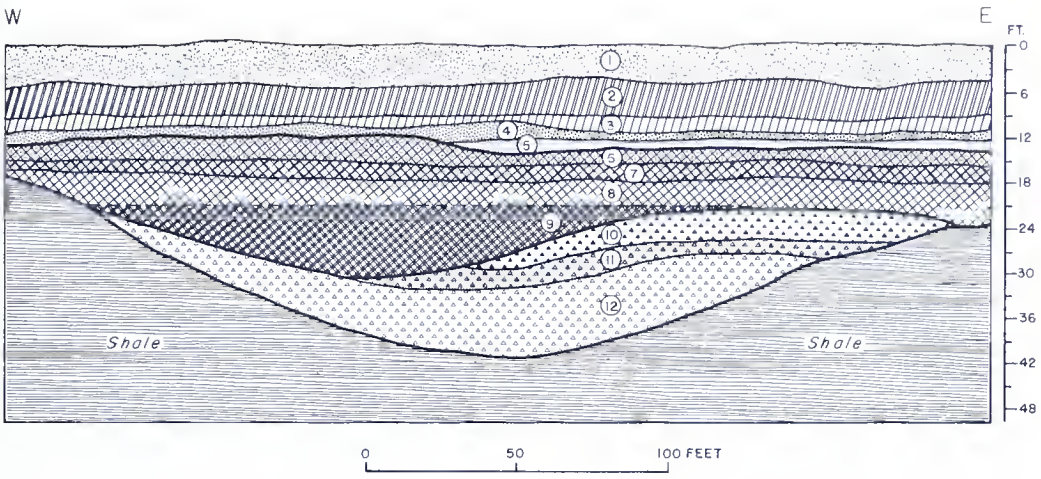


Figure 17. Sketch of glacial deposits in northeast corner of Ambrosia strip mine, 2 miles SE of Post Office in Grove City, Pine Twp., Mercer Co.; 0.4 mile NNE of sections shown in Figures 18, 19 and 20.

1. Till, weathered, and colluvium, soil at top.
2. Till, yellow brown, calcareous, KENT.
3. Till, brownish gray, calcareous, KENT (3140).
4. Sand, calcareous.
5. Till, "purple-pink", fine, extremely calcareous (3141).
6. Till, somewhat weathered, leached, TITUSVILLE I.
7. Till, olive brown, calcareous, TITUSVILLE I.
8. Till, gray, coarse, calcareous, TITUSVILLE I (3142).
9. Till, gray, stony, tough, calcareous, TITUSVILLE II (3143).
10. Till, brown, clayey, much weathered, top is truncated paleosol, MAPLEDALE.
11. Till, gray brown, coarse, noncalcareous, but fresh, MAPLEDALE (3144).
12. Till, gray brown, not coarse, faintly calcareous, MAPLEDALE II (3145).

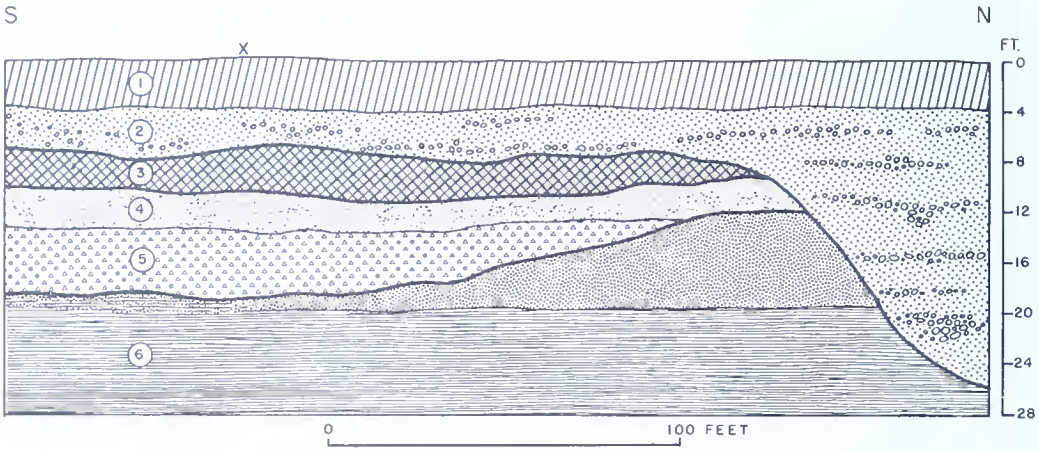


Figure 18. Sketch of glacial deposits exposed in 1966 in west wall of Ambrosia strip mine, 0.4 mile SSW of section shown in Figure 17.

1. Till, yellow brown, noncalcareous, soil at top, **KENT.**
2. Sand and gravel, calcareous, pro-**KENT.**
3. Till, gray brown, calcareous, **TITUSVILLE.**
4. Loam, clayey and stony, paleosol.
5. Till, yellow brown, noncalcareous but fresh, many angular and rounded cobbles, rare crystallines, **MAPLEDALE.**
6. Sandstone and shale.

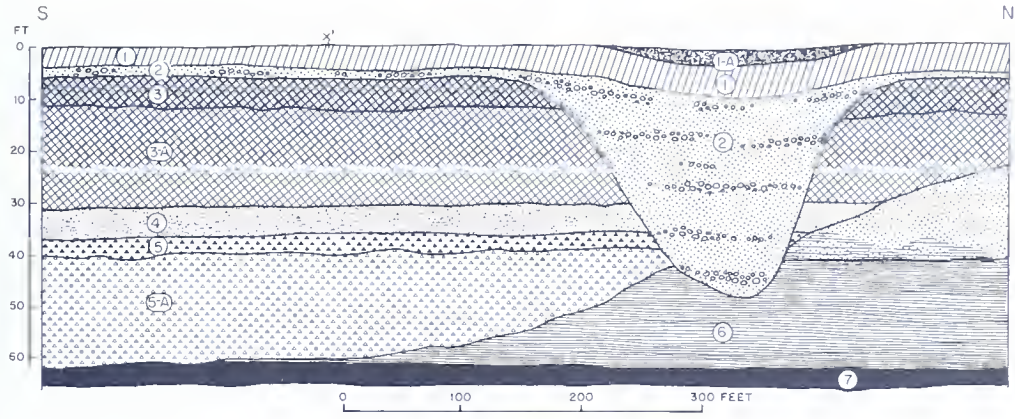


Figure 19. Sketch of glacial deposits in west part of strip mine just east of airport, 2 miles SE of Grove City, Pine Township, Mercer County, 0.4 mile SSW of section in Figure 17 (3140-45).

1-A. Peat and muck. (Note that compaction of channel fill has resulted in surface depression).

1. Till, yellow-brown, noncalcareous, soil at top, KENT.
2. Gravel and sand, gray and calcareous in channel, pro-KENT.
3. Till, olive-brown, calcareous, TITUSVILLE.
3-A. Till, gray, calcareous, with sand layers — probably two till sheets — TITUSVILLE.
4. Loam, clayey and stony, paleosol.
5. Till, yellow-brown, somewhat weathered, MAPLEDALE.
5-A. Till, fresh, gray, stony, noncalcareous, sandstone pebbles and cobbles, very rare crystallines, MAPLEDALE.
6. Shale, grading upward into sandstone, continuing for 1/4 mile north 15'-20' below ground surface.
7. Coal.

X'. Position of this section in E-W section, Figure 20.

Note: Also see Figures 18 and 20 in which numbers refer to same units. This face (1967) had advanced about 250 feet to the west of face in 1966, shown in Figure 18. Compare with Figure 18 to note deepening of gravel-filled channel from 28 to 48 feet; and with Figure 20 to note marked slope of rock surface to west and southwest; and especially the increase in thickness of Titusville and Mapledale units.

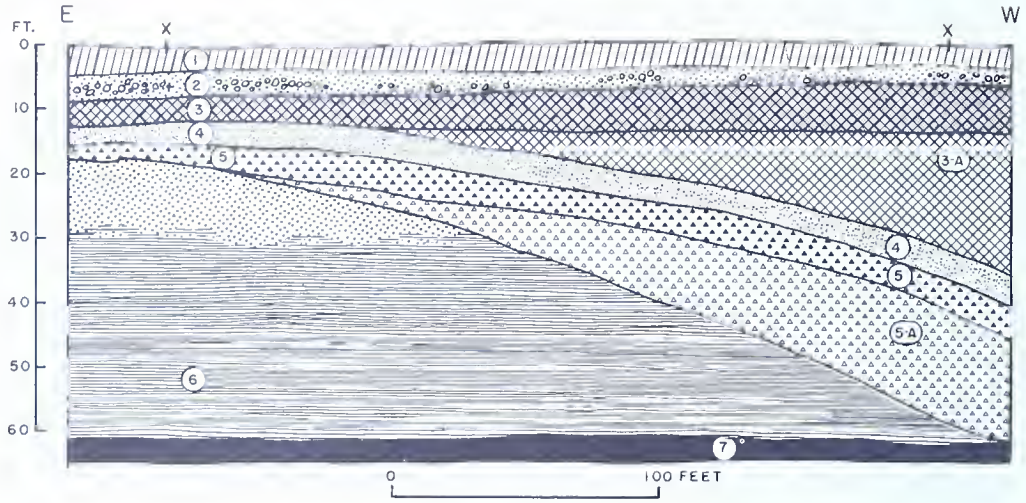


Figure 20. Reconstruction of E-W section through X of Figure 18 to X' of Figure 19 (1967) to show increase westward in the thickness of Titusville and Mapledale Tills. Reference numbers same as in Figures 18 and 19.

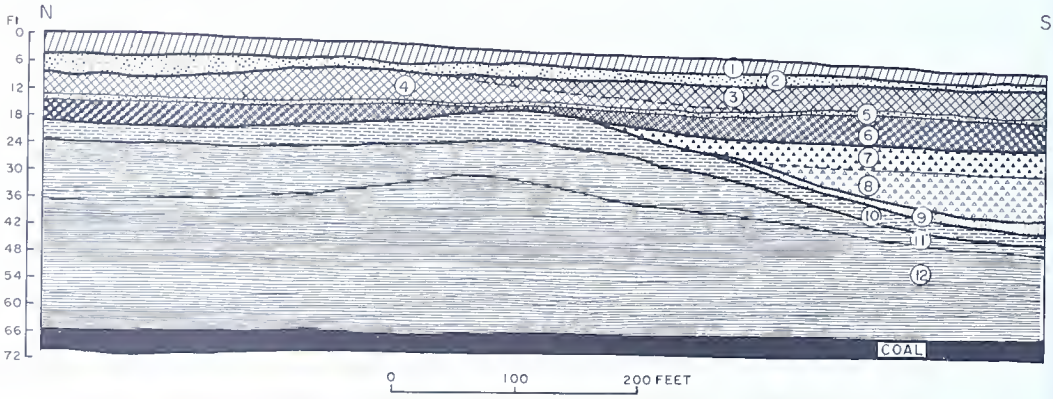


Figure 21. Section of glacial deposits in strip mine 1/3 mile S of Valcourt, Liberty Twp., Mercer Co.

1. Till and soil, KENT.
2. Sand.
3. Till, olive brown, leached in upper part, TITUSVILLE.
4. Till, olive gray, calcareous, (3184), 37% sand, 25% clay, TITUSVILLE I.
5. Sand, from 16 to 12 inches thick.
6. Till, gray to drab gray, (3185), 49% sand, 15% clay, TITUSVILLE II.
7. Paleosol, truncated, on much weathered brown till, MAPLEDALE.
8. Till, dark gray, fresh, but noncalcareous, (3186), 36% sand, 27% clay, MAPLEDALE.
9. Paleosol, truncated, and very clayey, on intensely weathered till, SLIPPERY ROCK.
10. Silty, clay, orange red to strong brown, no foreign pebbles, partly iron cemented plinthite, definite contact with shale below, PREGLACIAL ?
11. Shale, weathered, brown.
12. Shale gray.

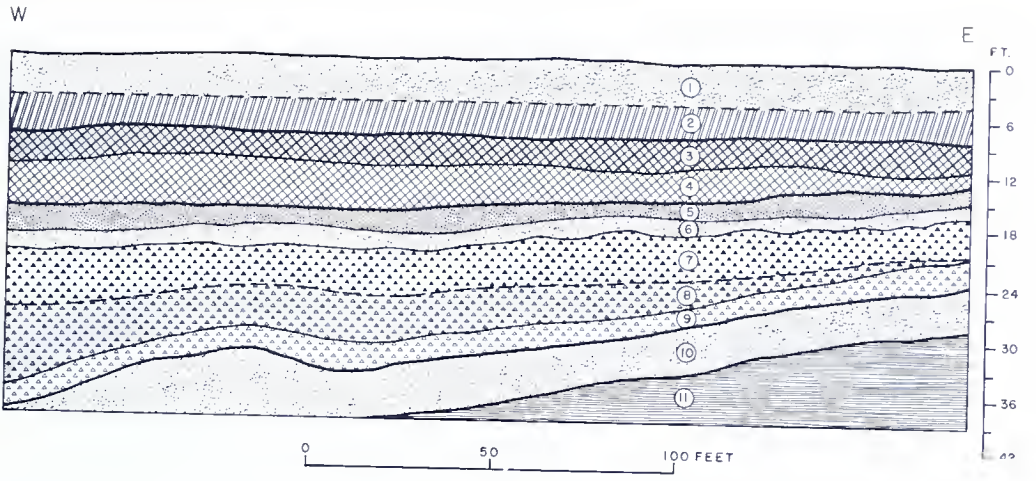


Figure 22. Sketch of glacial deposits in stripping of Vanport Stone Co. quarry, Courtneys Mills, Liberty Township, Mercer County, 3 miles N of Slippery Rock.

1. Weathered till and gravel.
2. Yellow brown till, calcareous, KENT.
3. Olive brown till, calcareous, TITUSVILLE.
4. Olive gray till, calcareous, TITUSVILLE (3149, 3189).
5. Weathered sand.
6. Till, much weathered, lower part of paleosol, MAPLEDALE.
7. Till, brown, upper part much weathered, MAPLEDALE.
8. Till, brown, stony, fresh, but noncalcareous, MAPLEDALE (3198, 3199).
9. Gray till, stony, fresh, but noncalcareous, MAPLEDALE (3150, 3200).
10. Till and colluvium, much weathered, upper part is paleosol, SLIPPERY ROCK.
11. Shale.

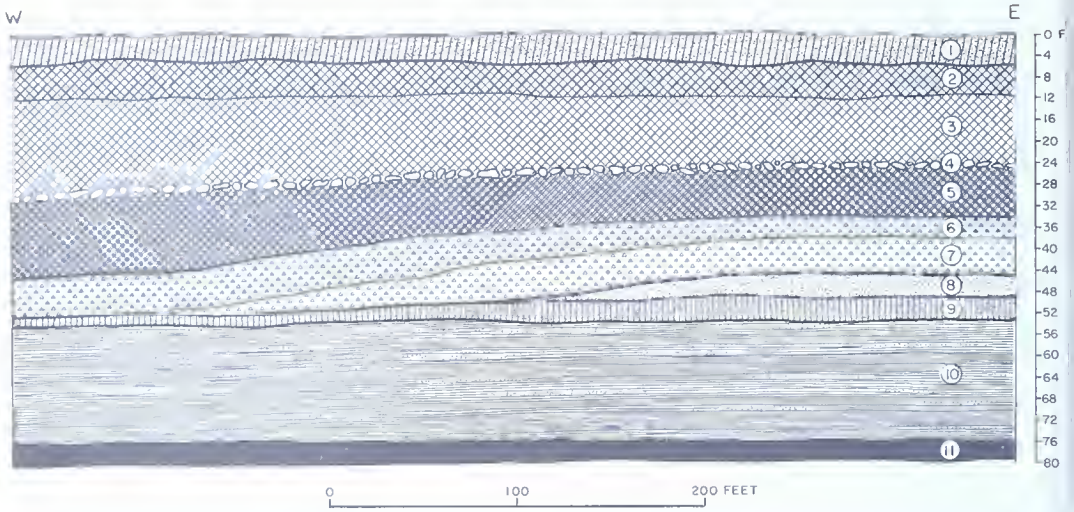


Figure 23. Section of glacial deposits in strip mine just west of rest park on W side of Interstate Highway I-79, 3 miles N of Plain Grove, Plain Grove Twp., Lawrence Co.

1. Till, weathered, yellow brown, and soil, KENT.
2. Till, olive brown, noncalcareous in upper part, TITUSVILLE I.
3. Till, olive gray, calcareous, TITUSVILLE I.
4. Stone line.
5. Till, olive gray, calcareous, TITUSVILLE II.
6. Paleosol, truncated, and till, yellow brown, weathered, MAPLEDALE.
7. Till, gray, noncalcareous or very weakly calcareous, MAPLEDALE.
8. Paleosol, till, and colluvium, deeply weathered, SLIPPERY ROCK.
9. Paleosol, very clayey, no foreign pebbles, grades into shale, deeply weathered, pre-SLIPPERY ROCK (preglacial?).
10. Shale, sandy.
11. Coal.

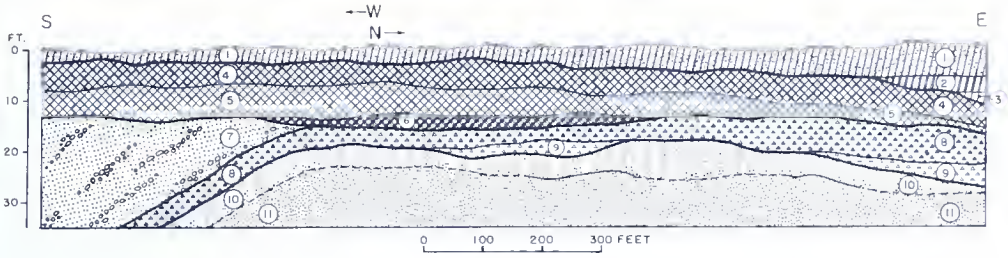


Figure 24. Sketch of glacial deposits in Testa Bros. strip mine 2 miles NW of Raymilton, Sandy Lake Township, Mercer County.

1. Till, stony, and soil, KENT.
2. Till, yellow brown, stony, calcareous KENT (2533).
3. Till, gray, stony, calcareous KENT (2534).
4. Till, olive brown, silty, sandy, noncalcareous, TITUSVILLE.
5. Till, olive brown, calcareous, TITUSVILLE (2535, 2537).
6. Till, olive gray, calcareous, TITUSVILLE (2538).
7. Sand and gravel in irregular and steeply dipped beds, pro-TITUSVILLE.
8. Till, dark brown, upper part much weathered, basal paleosol preserved at a few places, MAPLEDALE (at base 2539).
9. Till, gray, noncalcareous, MAPLEDALE (2536).
10. Sandy material, much weathered, some rounded pebbles, SLIPPERY ROCK (?).
11. Sandstone.

(Note change in direction of section at W/N)

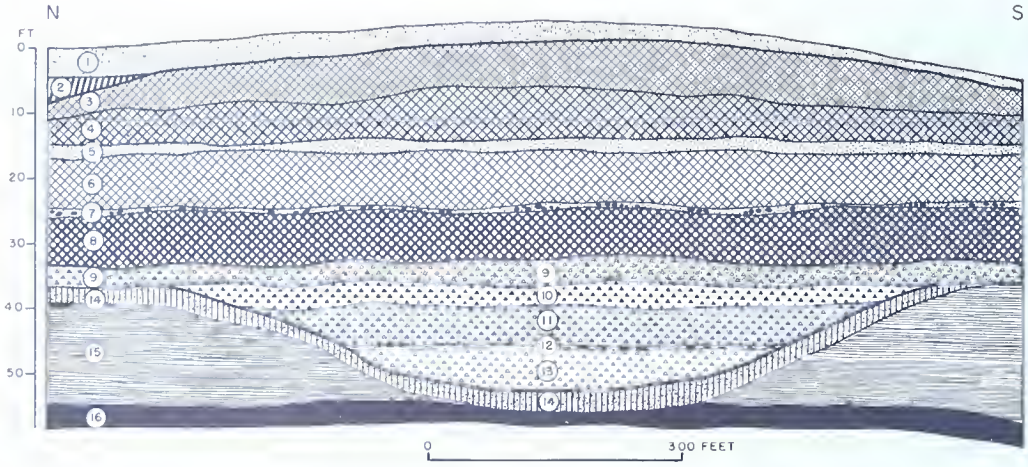


Figure 25. Sketch of glacial deposits in strip mine 0.4 mile W of Liberty Township, 0.4 mile N of Lawrence County, 0.2 mile S of E-W road, Springfield Township, Mercer County.

1. Soil and till, yellow brown, sandy, upper part disturbed, **KENT.**
2. Till, yellow brown, sandy, calcareous, **KENT (2431).**
3. Till, olive brown, sandy, very hard, noncalcareous, **TITUSVILLE.**
4. Till, olive brown and olive gray, calcareous, **TITUSVILLE I (2430).**
5. Sand, gray, water-bearing; zone of severe slumping of overlying material.
6. Till, "bright" gray, sandy, sand and pebbles at base, calcareous, **TITUSVILLE II (2429).**
7. Sand and pebbles.
8. Till, gray-brown, hard, pebbly, calcareous, **TITUSVILLE III (2428).**
9. Loam, stony and sandy, hard, yellow-orange to brown, thickness ranges from 2' to 4', **MAPLEDALE, PALEOSOL.**
10. Till, olive brown, very hard, very stony, very rare crystalline pebbles, noncalcareous, **MAPLEDALE I.**
11. Till, gray, hard, sandy, pebbly, but very few crystallines, noncalcareous, **MAPLEDALE I (2427).**
12. Clay and silt, with weathered shale and coal fragments.
13. Till, gray, silty — with many sand streaks, very rare crystallines, slowly calcareous, **MAPLEDALE II (2426).**
14. Weathered shale, with a few pebbles, **SLIPPERY ROCK ?**
15. Shale.
16. Coal.

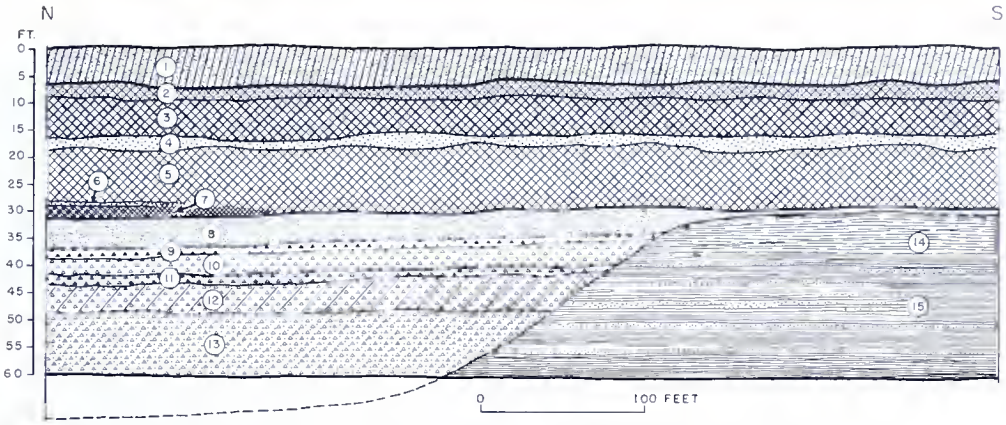


Figure 26. Section of glacial deposits in strip mine 1¾ miles SW of Perrine Corners, Worth Twp., Mercer Co.

1. Weathered till, KENT.
2. Till, olive brown, (2388), 56% sand, 13% clay, TITUSVILLE I.
3. Till, olive gray, (2387), 57% sand, 13% clay, TITUSVILLE I.
4. Sand, ranges from 6 to 24 inches thick.
5. Till, "bright" gray, (2385), 46% sand, 25% clay, TITUSVILLE II.
6. Sand, 2 to 6 inches thick.
7. Till, drab gray (2385X), 50% sand, 17% clay, TITUSVILLE III.
8. Paleosol (For detail see Figure 3) Note: very thin at south, where it is only a few pebbles in residual soil on shale.
9. Till, yellow brown, much weathered, MAPLEDALE.
10. Till, olive brown, fresh, but noncalcareous, MAPLEDALE.
11. Till, drab gray, noncalcareous, (2384), 52% sand, 15% clay, MAPLEDALE.
12. Till, gray, calcareous, (2382), 49% sand, 16% clay, MAPLEDALE II (?); at base 1 to 3 inch layer of lilac gray sand, highly calcareous, (2382).
13. Till, olive gray, very calcareous, (2382 A), 54% sand, 15% clay, MAPLEDALE III(?)
14. Weathered shale.
15. Shale and sandstone.

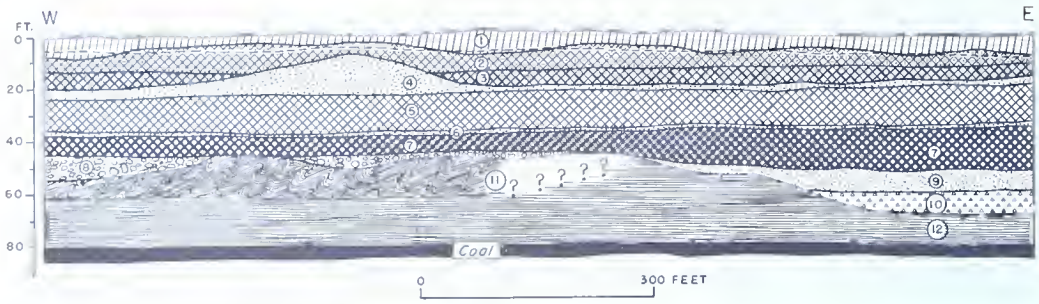


Figure 27. Section of glacial deposits in strip mine ½ mile S of Filers Corners, Lake Twp., Mercer Co.

1. Till, yellow brown, very silty soil at top, basal 1 foot calcareous where thickness greater than 6 feet, (2397), 40% sand, 19% clay, KENT.
   Note: Dashed line is depth of leaching.
2. Till, olive brown, calcareous, (2396), 41% sand, 18% clay, TITUSVILLE I.
3. Till, olive gray, calcareous, TITUSVILLE I.
4. Sand, pebbly, brown in upper part, gray in lower, note buried kame - 400 yards farther south similar buried sand kames at this horizon.
5. Till, "bright" gray, (2395), 51% sand, 16% clay, TITUSVILLE II.
6. Sand, gray ranges from 6 to 12 inches thick.
7. Till, very dark gray, (2394), 47% sand, 17% clay, TITUSVILLE III.
8. Gravel, cobbly to sandy, rusty red to strong brown, partly iron cemented, severely weathered and clayey.
9. Basal paleosol and weathered till, yellow brown, very clayey.
10. Till, gray, coarse, (3157), 47% sand, 16% clay, MAPLEDALE.
11. Shale, crumpled and shoved, "Jura structure", sharp sole at base.
12. Shale.

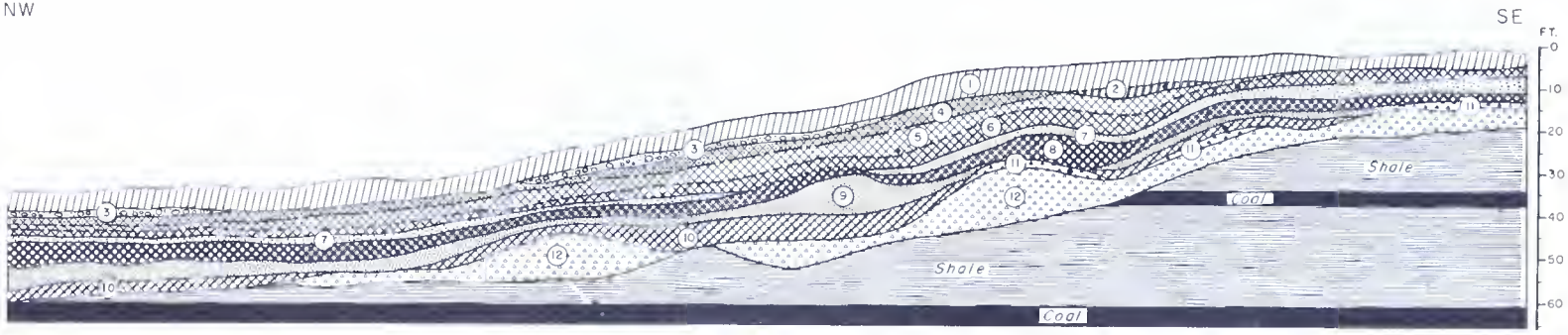


Figure 28. Sketch of glacial deposits in strip mine 1 mile N of New Galilee, adjacent to Pennsylvania Turnpike, Big Beaver Township, Beaver County.

1. Till, olive-brown to yellow-brown, noncalcareous, weathered, sandy, KENT.
2. Till, as above, calcareous, KENT (2754).
3. Sand and gravel, strong brown, weathered, noncalcareous.
4. Till, olive-brown, rusty, weathered, noncalcareous, TITUSVILLE I.
5. Till, olive-brown, rusty along joints, calcareous, TITUSVILLE I (2755).
6. Till, olive-gray, stained in joints, TITUSVILLE I (2756).
7. Sand, rusty-brown, calcareous, upper part contorted.
8. Till, olive-gray, sandy, pebbly, TITUSVILLE II (2757).
9. Sand, reddish-brown and gray, calcareous.
10. Till, olive-gray, sandy, rock and coal fragments in base, TITUSVILLE III (2758).
11. Till, yellowish-brown, highly weathered, MAPLEDALE (2759).
12. Gravel, reddish-brown, crystallines rare, weathered, MAPLEDALE.

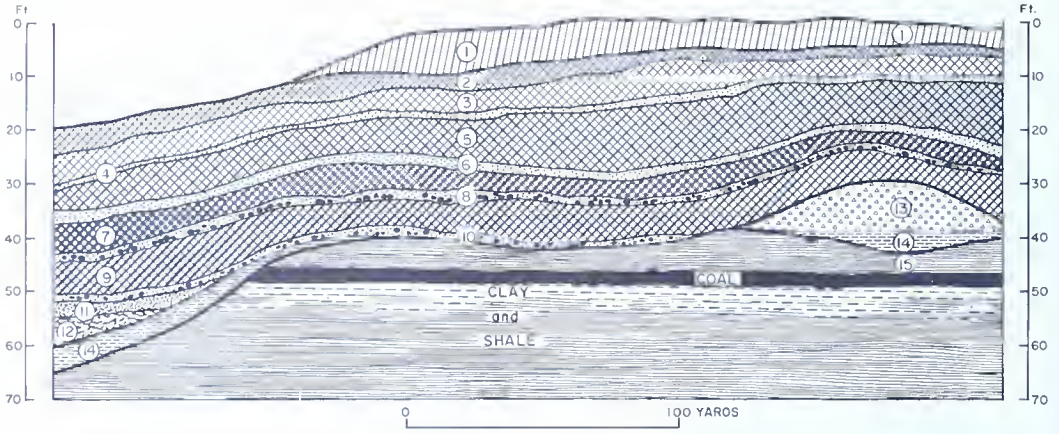


Figure 29. Sketch of glacial deposits in clay strip mine, 3 miles SSE of Mt. Jackson, 0.4 mile E of Derringer Corners, North Beaver Township, Lawrence County.

1. Till, yellow-brown, sandy-silty, calcareous in lower part where over 6' thick, KENT.
2. Till, olive-brown, rusty, pebbly, noncalcareous, paleosol and colluvium in upper part, TITUSVILLE I.
3. Till, olive-brown, calcareous, TITUSVILLE I (2864.)
4. Sand.
5. Till, olive-gray-brown and olive-gray, calcareous, massive silty, no staining, calcareous, TITUSVILLE II (2865, 2866, 2867).
6. Sand, yellow-brown, silty, calcareous.
7. Till, olive-gray, sandy, pebbly, calcareous, TITUSVILLE III (2868).
8. Gravel and sand, gray.
9. Till, olive-gray, compact and tough, sandy lenses, calcareous, TITUSVILLE IV (2869).
10. Sand and gravel, brown, clayey, calcareous.
11. Till, olive-gray, hard, stony, calcareous, (2870) TITUSVILLE V.
12. Till, olive-brown to olive-gray, tough, compact, calcareous, TITUSVILLE V (2871).
13. Till, brown, bricklike, noncalcareous, MAPLEDALE (2872).
14. Till, very light-gray-brown, weathered, noncalcareous.
15. Shale.

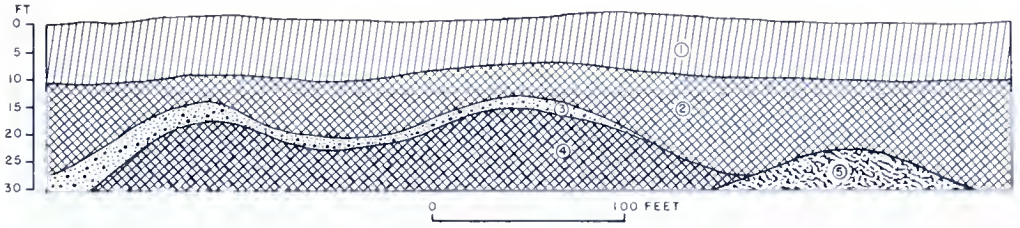


Figure 30. Section of glacial deposits in strip mine 2 miles SW of Perrine Corners, Worth Twp., Mercer Co.

1. Till, brown and olive brown (inaccessible on wall) KENT and TITUSVILLE.
2. Till, gray, TITUSVILLE I (2389).
3. Sand and fine gravel.
4. Till, brown, upper 2 feet leached, TITUSVILLE II.
5. Paleosol on till and colluvium, all intensely weathered, very rare foreign pebbles, MAPLEDALE.

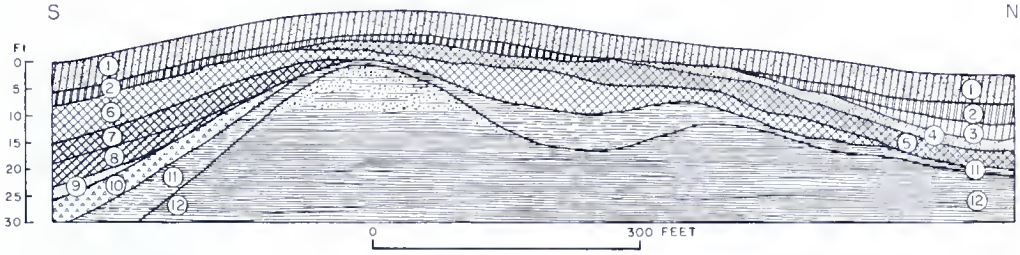


Figure 31. Sketch of glacial deposits in cuts for Interstate Highway 79, 1 mile W of Pardoe, Findley Township, Mercer County.

1. Weathered till and soil, KENT, upper 2 feet is silt.
2. Till, dark yellow-brown, calcareous, KENT (2523).
3. Till, gray, KENT.
4. Sand, yellow, pro-KENT.
5. Till, olive-brown, noncalcareous, base of paleosol preserved at places, TITUSVILLE.
6. Till, olive-brown, calcareous, TITUSVILLE (2524).
7. Till, gray, TITUSVILLE (3128).
8. Stony rubble and gray till, basal TITUSVILLE.
9. Paleosol, basal part.
10. Till, gray and brown, with weathered bedrock masses, MAPLEDALE (3129).
11. Shale, weathered, weathering pre-MAPLEDALE?
12. Shale, very sandy in highest part.

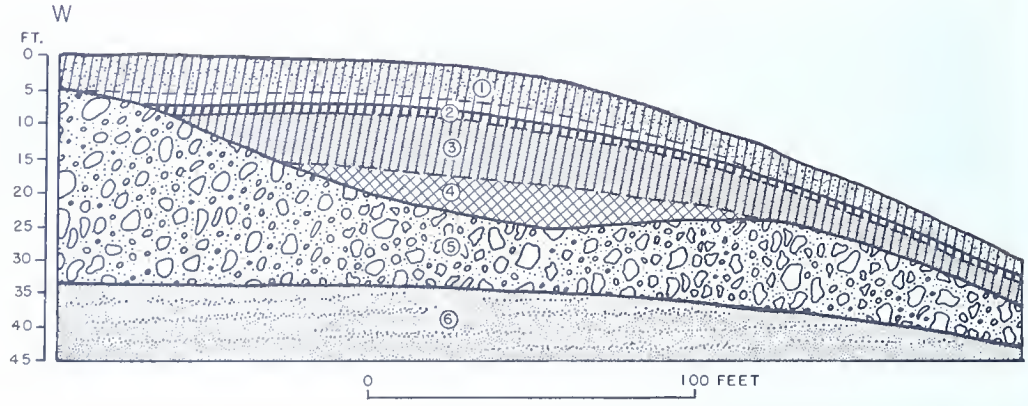


Figure 32. Section of glacial deposits above N end of Shenango Dam, ½ mile east of Sharpsville, Hickory Twp., Mercer Co.

1. Till, upper part weathered, with soil at top; lower part, fresh, yellow-brown, KENT (dashed line indicates depth of leaching).
2. Truncated paleosol and severely weathered till.
3. Till, olive-brown, weathered, TITUSVILLE.
4. Till, olive-brown, calcareous, TITUSVILLE.
5. Gravel, brown, cobbly to coarse bouldery, upper part weathered, pieces mainly sandstone, MAPLEDALE.
6. Sandstone and siltstone.

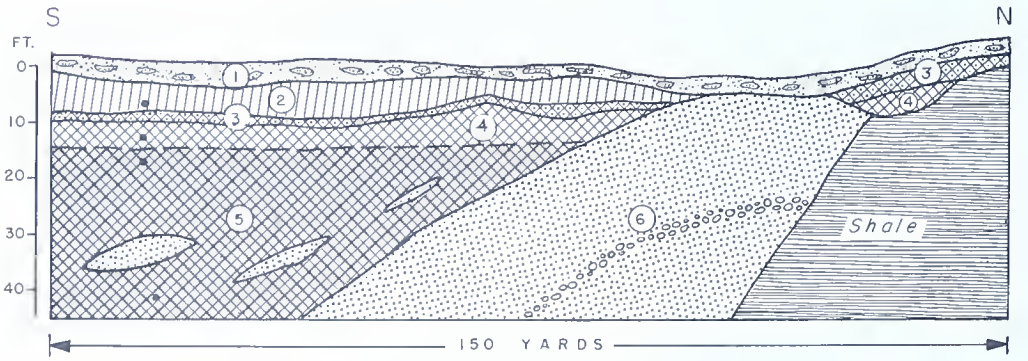


Figure 33. Sketch of glacial deposits in strip mine across tributary valley to Madden Run, 1½ miles SE of Enon Valley, Darlington Township, Beaver County.

1. Soil and colluvium, reddish-brown, much weathered, many sandstone channers.
2. Till, yellowish-brown, lower 1½ feet calcareous, KENT (2736).
3. Till, olive-brown, rusty, weathered, TITUSVILLE.
4. Till, olive-brown, stained along joints, calcareous, TITUSVILLE (2737).
5. Till, gray to olive gray, with sand lenses TITUSVILLE (2738, 2739).
6. Sand and gravel, yellowish-brown to reddish-brown, upper part considerably weathered, pre-TITUSVILLE?

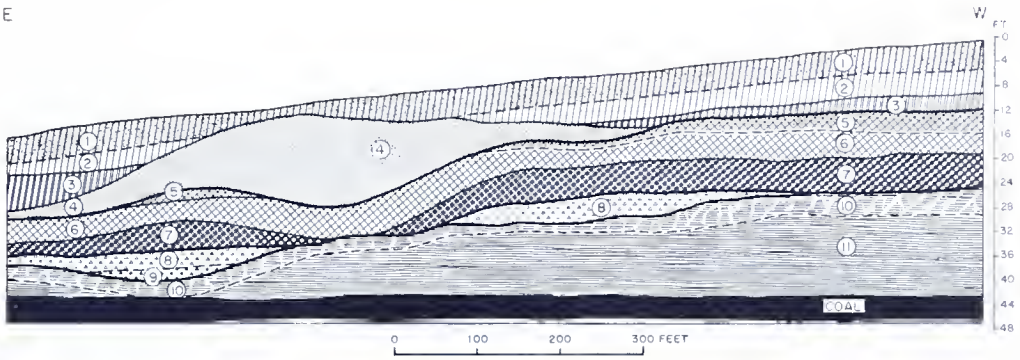


Figure 34. Sketch of glacial deposits in strip mine ¼ mile E of Kerrs Corners, 2 miles E of Grove City, Pine Township, Mercer County.

1. Till, weathered, with silt loam soil, KENT.
2. Till, yellow-brown, sandy, calcareous, KENT (2514).
3. Till, gray, sandy, calcareous, KENT (2515).
4. Sand, brown, very calcareous, pro-KENT.
5. Till, weathered, base of paleosol preserved in a few places, TITUSVILLE.
6. Till, olive-brown, calcareous, TITUSVILLE.
7. Till, olive-gray, calcareous, TITUSVILLE (2516, 2517).
8. Till, much weathered, base of paleosol preserved in places, MAPLEDALE.
9. Till, drab gray, fresh, mostly noncalcareous, MAPLEDALE (2518).
10. Shale, much weathered, with rounded rock fragments of possible glacial origin, SLIPPERY ROCK?
11. Shale and shaly sandstone, gray.

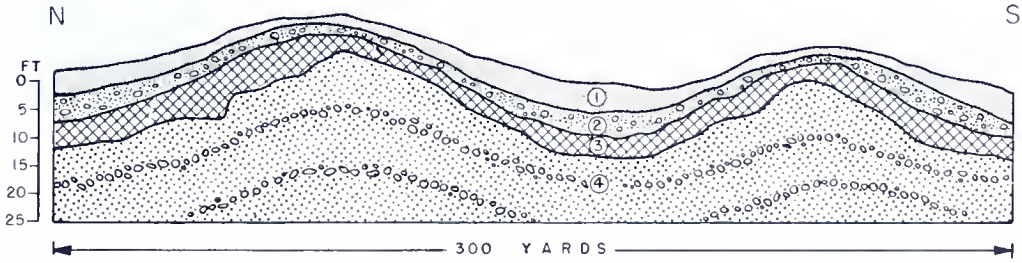


Figure 35. Sketch of glacial deposits in gravel pit at road fork 1 mile S of New Galilee, Big Beaver Township, Beaver County.

1. Silt, yellow-brown, weathered, (thicker in depressions).
2. Sand and gravel, reddish-brown, calcareous in base where thickest.
3. Till, olive-brown, calcareous near base, TITUSVILLE (2740).
4. Sand and gravel, gray-brown, calcareous.

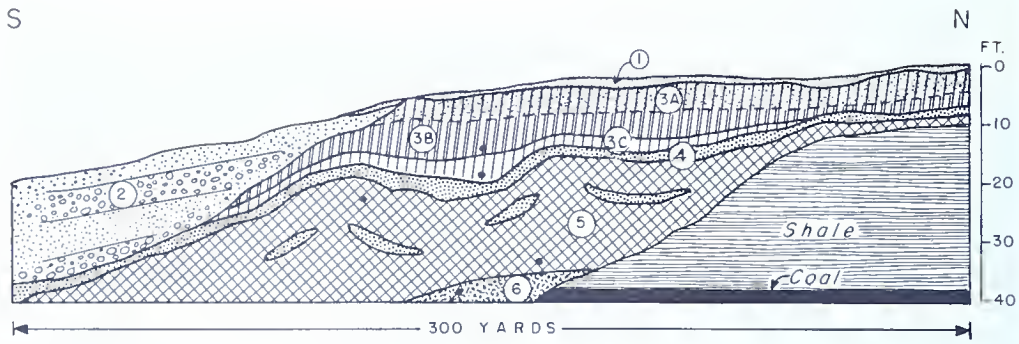


Figure 36. Sketch of glacial deposits in strip mine 3 miles NW of Enon Valley, ½ mile E of Ohio-Pennsylvania line, Little Beaver Township, Lawrence County, Pennsylvania.

1. Silt, tan, some colluvium included.
2. Sand and gravel, weathered in upper part.

3A. Till, olive-brown to yellow-brown, weathered, noncalcareous, KENT.

3B. Till, olive-brown to brown, calcareous, KENT (2749).

3C. Till, gray, calcareous, KENT (2750).

4. Sand, gray, fine, calcareous, water-bearing.
5. Till, olive-gray, pebbly, calcareous, associated with sand and gravel in buried kame-like hills, TITUSVILLE (2751, 2752).
6. Till, dark gray, few pebbles (2753).

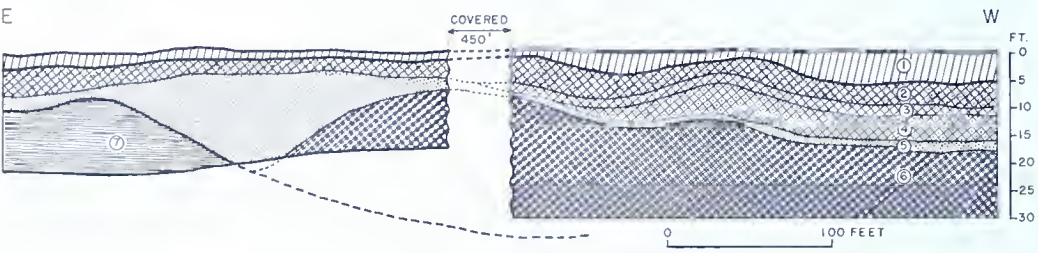


Figure 37. Section of glacial deposits in strip mine ½ mile S of Nesbit Corners, ¾ mile SE of Jackson Center, Jackson Twp., Mercer Co.

1. Till, yellow brown, leached, lower part fresh, KENT.
2. Till, olive brown, leached, upper 2 feet more weathered than Kent Till above, TITUSVILLE I.
3. Till, olive brown, calcareous, (2393), 52% sand, 13% clay, TITUSVILLE I.
4. Till, dark gray, calcareous, (2392), 40% sand, 17% clay, TITUSVILLE I.
5. Sand, gray, calcareous, much thicker to east.
6. Till, very dark gray to brownish gray, (2391), 50% sand, 18% clay, TITUSVILLE II.
7. Shale.

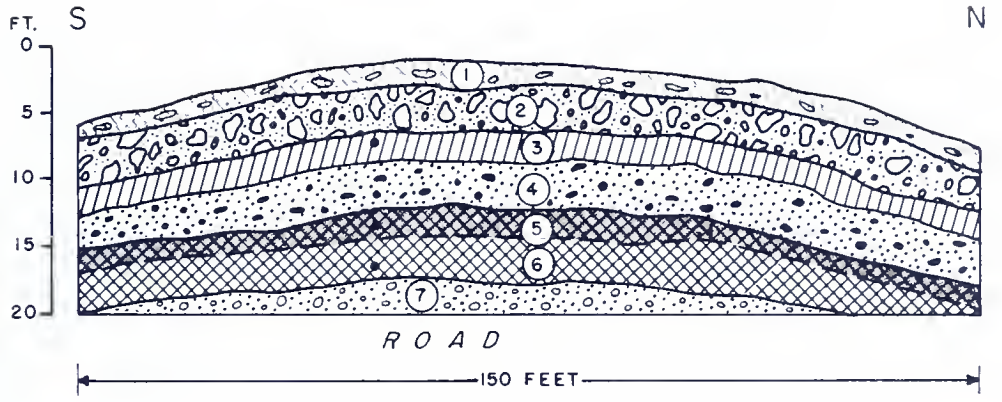


Figure 38. Sketch of glacial deposits in road cut 1 mile SE of Enon Valley, Darlington Township, Beaver County, Pennsylvania.

1. Colluvium, weathered.
2. Gravel and till, weathered.
3. Till, yellow-brown, slightly calcareous at base, KENT (2733).
4. Colluviated sand and gravel.
5. Till, olive-brown, calcareous, TITUSVILLE I (2734).
6. Till, drab olive-gray, TITUSVILLE I (2735).
7. Sand and gravel, yellow-brown, calcareous.

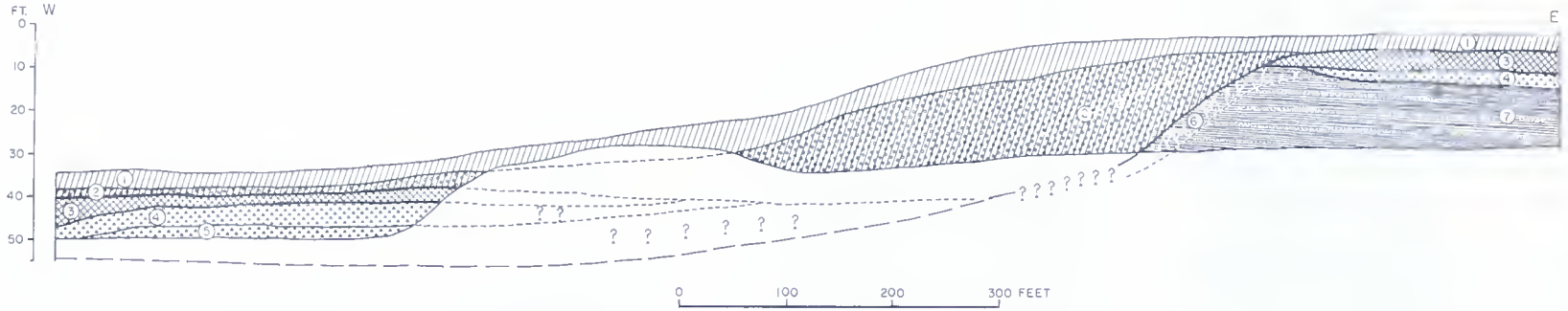


Figure 39. Sketch of glacial deposits in excavations for Route 8 and I-80 interchange, 1 mile N of Barkeyville, Irwin Township, Venango County.

1. Till and soil, KENT.
2. Sand and gravel; kames where thick and very extensive to north and south, KENT.
3. Till, olive-brown, noncalcareous, basal part fresh at extreme west end, TITUSVILLE.
4. Till, yellowish-brown, upper part is extremely weathered and is base of paleosol, MAPLEDALE.
5. Till, gray, noncalcareous, MAPLEDALE.
6. Shale and sandstone, much weathered.
7. Shale and sandstone.

Note: Inferred part of section, shown by dashed lines, based on spoil from refilled excavations.

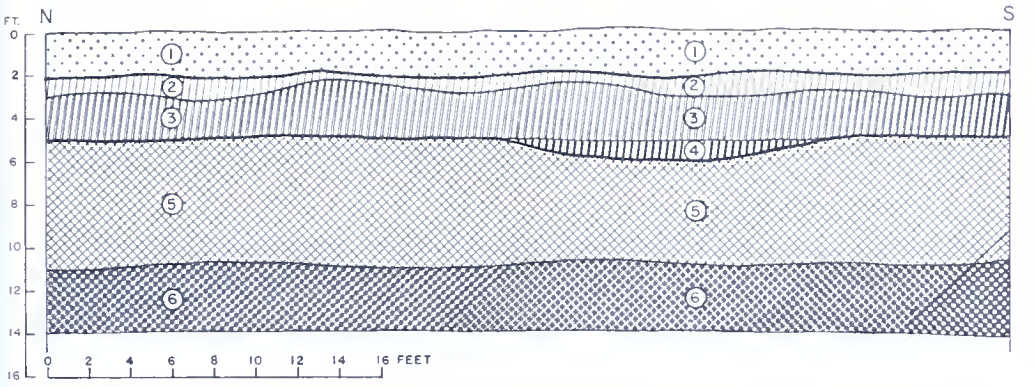


Figure 40. Sketch of glacial deposits exposed in excavation for new dormitory, Thiel College, Greenville, Mercer County.

1. Loam, clayey and much weathered till, brown, LAVERY.
2. Loam, yellow-brown, rubbly and with channers, abundant clay seams, KENT.
3. Till, weathered, KENT.
4. Till, yellow-brown, sandy, calcareous, KENT (2602).
5. Till, olive-brown, sandy, noncalcareous, TITUSVILLE.
6. Till, olive-brown, extremely hard, sandy, pebbly, calcareous, TITUSVILLE (2603).

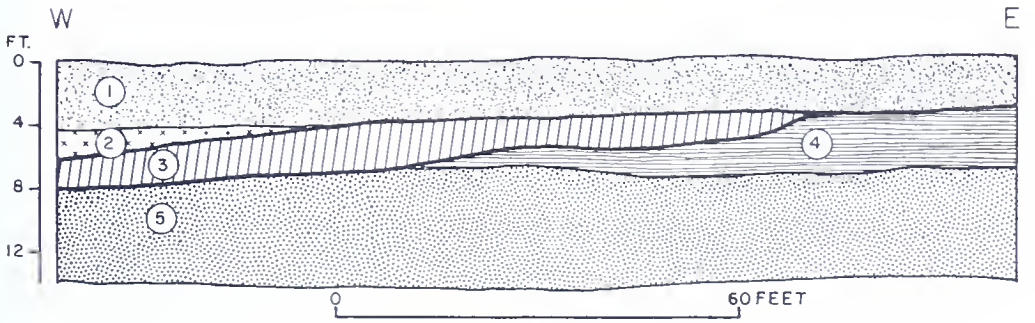


Figure 41. Sketch of glacial deposits in stripping above sandstone quarry, Quarry Hill, Hemphill Township, Mercer County, 1/8 mile W of highway, 2 miles SE of center of Greenville.

1. Soil and weathered till (lower 1½′ fresh, but noncalcareous).
2. Till, dark brown, silty, only very moderately pebbly, breaks in ½″ subcubical fragments, calcareous, LAVERY (2601).
3. Till, yellow brown, sandy, leached, KENT.
4. Shale.
5. Sandstone, many SE trending striations and grooves.

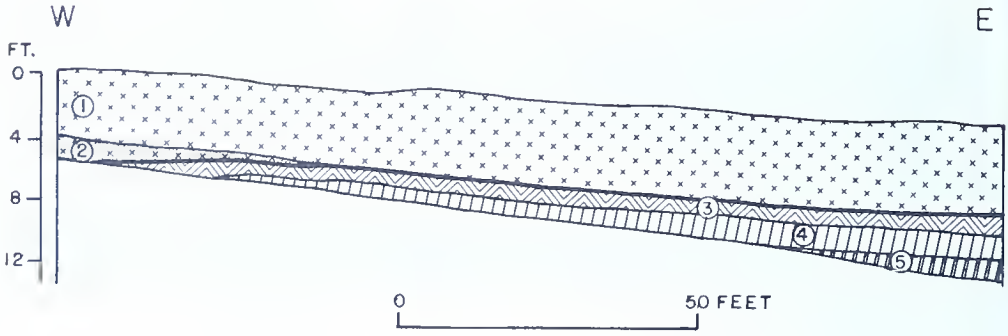


Figure 42. Sketch of glacial deposits in road cut ¼ mile south of southeast corner of borough limit, Union City, Erie County.

1. Till, leached, soil at top, LAVERY.
2. Till, silty, dark brown, calcareous, LAVERY (3242).
3. Disturbed zone with channers.
4. Till, sandy, yellow-brown, noncalcareous, KENT.
5. Till, sandy, yellow-brown, calcareous, KENT.

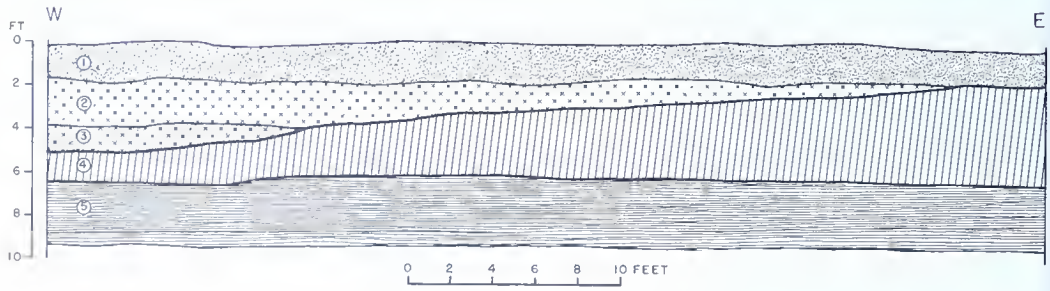
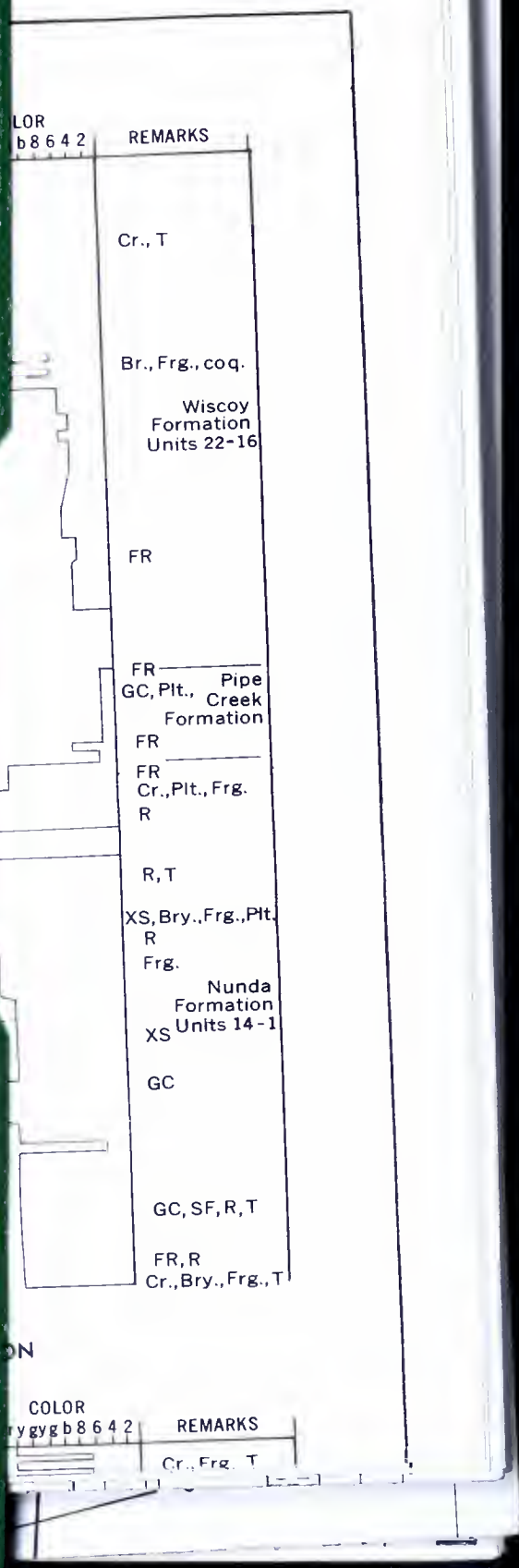


Figure 43. Sketch of glacial deposits in borrow pit 1 mile NW of center of Edinboro, Washington Township, Erie County.

1. Soil and weathered till.
2. Till, dark brown, noncalcareous, LAVERY.
3. Till, dark brown, silty, calcareous, LAVERY.
4. Till, yellow brown, sandy, noncalcareous, KENT.
5. Shale.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REMARKS
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Nunda Formation Units 14-1
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REMARKS
Cr., Frg., T